

**Assessing the Effect of Current and Future Climate Variability on Sorghum
and Wheat Production in Waghemra Zone of Amhara Regional State,
Ethiopia.**

By: Wagaye Bahiru



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Assessing the Effect of Current and Future Climate Variability on Sorghum and Wheat Production in Waghemra Zone of Amhara Regional State, Ethiopia

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DEDICATION

I dedicate this thesis manuscript to my lovely father Bahiru Abegaz and to my mother Alemitu Gebru for making me what I am today.

STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this thesis is my own work. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis and compilation of this thesis. Any scholarly matter that is included in the thesis has been given recognition through citation. This thesis is submitted in partial fulfillment of the requirements for MSc degree in Applied physics (Meteorology) at Adama Science and Technology University. The thesis is deposited in the Adama Science and Technology University library and is made available to borrowers under the rules of the library. I solemnly declare that this thesis has not been submitted to other institution anywhere for the award of any academic degree, diploma or certificate.

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BIOGRAPHICAL SKETCH

The author, Wagaye Bahiru, was born on July 1986 G.C in Ambasel Wereda, South Wollo Zone of Amhara National Regional State, Ethiopia, from his father Bahiru Abegaz and his mother Alemitu Gebru. He attended his elementary education at Marye Elementary School and

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LIST OF ABBREVIATIONS AND ACRONOMYS

AEZs	Agro-Ecological Zones
AgMIP	Agricultural Model Inter-comparison and Improvement Project
ANRS	Amhara National Regional State
AOGCM	Atmosphere-Ocean General Circulation Models
AR4	Fourth Assessment report
AR5	Fifth Assessment Report
CGRD	Climate and Geospatial Research Directorate
CMIP5	Coupled Model Inter-Comparison project phase five
CO ₂	Carbon dioxide
CSA	Central Statistical Agency
CV	Coefficient of variation
DOY	Day of the Year
EIAR	Ethiopian Institutes of Agriculture Research
EN	El Nino
ENSO	El Nino –South Oscillation
EOS	End of the Season
GCM	General Circulation Model
GDP	Gross Domestic Product
GHGs	Green House Gases
ICRISA	International Crop Research Institute for Semi-Arid Tropics
INSTAT	Interactive Statistical Processing Package
IPCC	Inter governmental panel on climate change
ITCZ	Inter Tropical Convergence Zone
JJAS	June July August September

LGP	Length of Growing Period
MK	Mann Kendall trend test
MOA	Ministry Of Agriculture
Met	Meteorology
NMA	National Meteorological Agency
NMSA	National Meteorological Services Agency
NOAA	National Oceanic and Atmospheric Administration
PCI	Precipitation Index
RCM	Regional Climate Model
RCPs	Representative Concentration Pathways
RMSE	Root Mean Square Error
SD	Standard Deviation
SOS	Start of Season
SRA	Standardized Rain fall Anomaly
SRES	Special Report on Emission Scenarios
SSA	Sub Saharan Africa
SST	Sea Surface Temperature
UNDP	United Nation Development Program
WMO	World Meteorological Organization

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Abstract

Climate variability has a direct and in most cases adverse influence on quality and quantity of agricultural crop production. This study aims at understanding the effect of the past and future climate variability on rain-fed wheat and sorghum production in Waghemra zone, Ethiopia. The observed daily rainfall and temperature data were collected from National Meteorological Agency, Ethiopia for the period of 1986-2016 and the future projected daily rainfall and temperature data were downscaled from 20 General Circulation Models under Rcp4.5 and Rcp8.5 emission scenarios for the period 2050s and 2080s. Temporal variability of rainfall and temperature were analyzed using coefficient of variation and standardized anomaly method. Trends were evaluated using Sen's slope estimator and Mann-Kendall trend test methods using XLSTAT 2014 software. To evaluate the effect of climate variability on crop yields using multiple regression analysis. The analysis revealed that rainfall exhibited large inter-annual and seasonal variation in the amount and distribution. The rainfall trends showed decreasing in Belg while increasing in both annual and Kiremt. However, the detected trends are non-significant. On the other hand minimum and maximum temperature showed significantly increasing trends during annual and seasonal time scales. It is very likely that the number of cold days and nights has decreased and the number of warm days and nights has increased. The result of the regression analysis shows rainfall and temperature jointly contributed 84% and 86% in explaining the variations in the yield of wheat and sorghum per hectare respectively in the Waghemra Zone. Projections for future climate suggested that annual rainfall will likely be decreasing by 1.6-2.8% by 2050s and 2080s under Rcp4.5 emission scenario while that of Rcp8.5 scenario showed increment by 1.1-4.3% for the period 2050s and 2080s respectively. The mean annual temperature is projected to be increased within the range of 1.9-2.4 °C under Rcp4.5 for the period 2050s and 2080s respectively. Similarly under Rcp 8.5 scenario the mean annual temperature will be also increasing by 2.8-4.1 °C for the period of 2050s and 2080s respectively. The past and future climate trends, especially in terms of rainfall and temperature and its variability pose major risks to rain-fed agriculture. Specific adaptation strategies are needed for the study area to cope with the risks, sustain farming and improve food security.

Keywords: Climate variability, Multiple Regression, Crop production, Waghemra Zone, Ethiopia

1. INTRODUCTION

1.1 Background of the study

Climate change and variability is already having a significant impact on the agricultural sector which is an important activity in the developing world; as the sector is dominated by rain-fed crop production and household's food security is particularly vulnerable to climate variability (Lamboll et al., 2011). Climate change and variability poses huge challenges to the global economy and to social development. Its impacts will disproportionately affect sub-Saharan African countries such as Ethiopia because their economies are highly dependent on climate-sensitive activities such as rain-fed agriculture. The effects of climate variability come in the form of rising temperatures, unpredictable rainfall, loss of soil moisture, and increased evaporation and transpiration, among other effects (Ofori-Sarpong, 2011). Climate variability has had a significant impact on agriculture in many parts of the world (IPCC, 2007). Drastic changes in rainfall patterns coupled with rising temperatures result in unfavorable growing conditions and changes in the cropping calendar, thereby modifying growing seasons which can subsequently reduce productivity (Manneh et al., 2010).

Climate variability and change impacts directly or indirectly on all economic sectors to some degree, but agriculture is among the sectors most sensitive and inherently vulnerable to climate variability (Boko et al., 2013; Muller et al., 2013; Wheeler and Braun, 2013). The changing rainfall pattern in combination with warming trends could make rain-fed agriculture more risky and aggravate food insecurity in Ethiopia. Climate variability, particularly rainfall variability and associated droughts have been reported as major causes of food insecurity and famine in Ethiopia (Thornton p.k., 2006; Conway and Demeke, 2011). The variability and/or changes in climate are most likely to bring about hazards such as high temperatures, heavy rainfall, dry spells/droughts, floods and windstorms, which will have deleterious impact on humans and the ecosystems on the globe (Vergni, L. and Todisco, F. 2011).

In countries like Ethiopia, agriculture contributes about 47% of the country's Gross Domestic Product (GDP) and more than 70 million people (85% of the Ethiopian population) depend on agriculture directly or indirectly for their livelihoods (Mundi, 2014). Therefore, any effect on agriculture will significantly affect the Ethiopian economy. Variability in climatic elements,

specially rainfall and temperature, may affect agricultural production as they influence the soil moisture and soil fertility, length of growing season and increased probability of extreme climatic conditions which would result in crop damage, lower yields, income losses, harvesting difficulties, increased pest activities and delayed seeding. Crop yield varies from season to season owing to variation in climate during the growing seasons (Bewket, 2009; Ayalew et al., 2012). Regional climates naturally fluctuate about the long-term mean. For example, rainfall variability occurs with regard to timing and quantity, affecting agriculture each year. It is clear that changes have occurred in the past and will continue to occur, and climate change modifies these variability patterns, for example, resulting in more droughts and floods.

The seasonal climate variability of Ethiopia, particularly rainfall, is influenced by weather systems of various scales; from meso-scales to the large scale, mainly El Nino-Southern Oscillation (ENSO) related phenomena (NMSA, 1996).

Many authors have documented how ENSO events have strongly linked with various atmospheric system and rainfall distribution over Ethiopia (Korecha, 2007). For instance, the principal cause of drought in Ethiopia is asserted to be the fluctuation of the global atmospheric circulation, which is triggered by sea surface temperature (SST) anomalies, occurred according to ENSO events. It has also been noted that the rainfall is highly variable in amount, distribution and becomes unpredictable across regions and seasons (Tesfaye, and Walker 2004; Tilahun, K.1999; Mersha, E.1999). This variability of rainfall and recurrent droughts in Ethiopia affects the lives of millions of people as livelihood of the people depends on rainfall.

Temperature and precipitation are two most important climate parameters that are most studied in climate research because of their immediate impact in various socioeconomic sectors (e.g. agriculture and hydrology), including human comfort (sayemuzzaman, 2014). Temperature and rainfall have therefore become important variables which can have direct and indirect effects on agricultural crops in general. Particularly, temperature is important to agriculture because it influences plant growth through photosynthesis and respiration, affects soil temperature, and controls available water in the soil. Germination, growth and development of crops are highly influenced by temperature.

Among the more powerful determinants of crop yield were rainfalls at the onset and at the cessation months of the growing season. According to Getaneh (2015) the impacts of rainfall on crop production in Ethiopia are closely related to its variability and occurrence of dry/wet spells during the crop growing periods. The National Meteorological Agency (2001) revealed that in Ethiopia climate variability and change is mainly manifested through the variability and decreasing trend in rainfall and increasing trend in temperature.

The main objective of the study was to assess the effect of current climate variability and future change possible implications on major crop production in the study area and local coping and adaptation mechanisms are vital to the effect of climate variations particularly characteristics of rainfall and temperature is therefore, crucial for planning and designing appropriate adaptation strategies.

1.2 Statement of the problem

Climate change and variability is a global issue that needs to be given proper attention because of its impacts on the agriculture and other aspects of socio-economies. A country like Ethiopia whose economy is heavily dependent on rain fed agriculture. Climate variability is one of the most important factors in explaining various socioeconomic problems such as yield reduction and food insecurity. According to Kirimi, (2013) climate change and climate variability affect the productivity of agricultural systems. Variability in climatic elements, specially rainfall and temperature, may affect agricultural production as they influence the soil moisture and soil fertility, length of growing season and increased probability of extreme climatic conditions which would result in crop damage, lower yields, income losses, harvesting difficulties, increased pest activities and delayed seeding. A small increase in temperature decreases agricultural production (IPCC, 2007). A similar study by Bewket.W, (2016) showed that among cereals grown in the central highlands of Ethiopia Sorghum and wheat productions shows high year-to-year variations due the effect of local climate variability.

The climate variability impact studies, particularly seasonal and annual variability and crop yield reduction has greater help for crop planning, for selection of crop varieties/ suitability, for crop management practices, for plant protection measures and related farm operations. For example the amount of rainfall received during the life period of a crop plays an important role in the final

product of the crops. However, there are only a few studies on the effects of climate variability on crop production in Ethiopia (Admassu, 2004; Bewket, 2009; Lemi, 2005). These studies are either at national or regional scales which mask local scale variability. Rain-fed agriculture is also predominant in Waghemra Zone but agricultural production is highly affected by climate variability and such studies are very limited. Waghemra Zone is one of the vulnerable regions in Ethiopia due to its reliance on climate sensitive sectors particularly agriculture, Hence changing rainfall pattern in combination with warming trends could make rain-fed agriculture more risky and aggravate food in security in the region. Wheat and sorghum crops are widely grown under rain-fed conditions in the study area. Hence, production and productivity of these crops are affected by climate variability. However, the link between crop production and climate variability are not adequately studied in the study area.

Therefore based on the above mentioned and other problems understanding the past and the future climate variability conditions particularly characteristics of rainfall and temperature is crucial for planning and designing appropriate adaptation strategies in the study area.

1.3 Objective of the study

1.3.1 General objective

The general objective of the study was to investigate the past and future climate variability and its effect on wheat and sorghum production in Waghmra Zone of Amhara regional state, Ethiopia.

1.3.2 The specific objectives of the study were:

- ✓ To characterize the climate of the study area
- ✓ To analyze the trend and variability of rainfall and temperature
- ✓ To determine the nexus between observed climate variables and crop production
- ✓ To assess the impact of future climate change on wheat and sorghum production.

1.4 Research questions

- ✓ How the trend of rainfall and temperature are characterized?
- ✓ To what extent do climate variability affects crop production?
- ✓ How is the relationship between climate variables and crop yields characterized?
- ✓ What will be the impact of future climate fluctuations on wheat and sorghum production under medium and high emission scenarios?

1.5 Scope of the study

The study was mainly focused on the analysis of climate variables such as temperature and rainfall and its effect on wheat and sorghum production in Waghemra zone. The study used climate data on respective observed variables for the period 1986-2016 and the future projected variables include for the period mid and end-century (2050s and 2080s). However, the observed crop yield data was covers for the period 2007-2016 due to lack of data. The study was not consider non climatic factors like soil type, fertilizer application, crop management practices, irrigation management, type of technology, surface run off ,pest and diseases etc.

1.6 Significance of the study

Climate variability adversely impacts crop production and imposes a major constraint on farming planning, mostly under rain fed conditions, across the world. The study of climate variability is crucial considering the fact that its impacts are numerous particularly rain-fed agriculture is at large. The main hazard in this livelihood is the shortage of water, which arises from inadequate rainfall, dry spells and early cessation of rains during critical crop growth and seed setting periods have negative impact on harvest and the resultant water shortage has led to the substantial decline in agricultural productivity. Climate information is also highly important in this regard. The findings of this study can be used as inputs for decision makers enable to select suitable crops/varieties, enable policy makers to get prepared to the negative impacts on crop production and as reference/baseline for further studies.

With the help of such information it is possible to increase agricultural productivity, efficient water resource utilization and natural resource conservation and also to take appropriate decision and mitigation strategy. So this study has an interesting insight to such advantageous climatic information and decisions.

2. LITERATURE REVIEW

2.1. Over View of Climate variability and Change

According to the World Meteorological Organization (WMO, 2011), climate variability represents variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. These climatic variations will have unexpected consequences with respect to frequency and intensity of precipitation and temperature variability for many regions of the Earth. Variability may be due to natural processes within the climate system (internal variability), or due to anthropogenic forcing (external variability).

Climate change: A change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing or to persistent anthropogenic changes in the composition of the atmosphere or in land use systems (IPCC, 2014). Natural and anthropogenic substances and processes that alter the Earth's energy budget are drivers of climate change. Radiative forcing (RF) is the net change in the energy balance of the Earth system due to some imposed perturbation (IPCC, 2013).

Future climate change impacts are derived using Global Climate Models (GCMs) to project future changes in climate. A Global Climate Model (GCM) combines a series of models of the Earth's atmosphere, oceans, and land surface. GCMs divide the earth into many layers and thousands of three dimensional gridded spaces. The climate models project possible future climate shifts under the conditions of the specific scenarios. Future scenarios of greenhouse gases are used as input to these models to explore how differing global concentrations of greenhouse gases are likely to affect important climatic variables such as temperature and precipitation. These models operate at large scales and are usually downscaled to higher resolution so that their outputs can be used as inputs to impacts models to explore how changes in climate might impact on specific sectors. For example downscaled output might be used as input to crop models to examine how changing temperatures may impact agricultural production, or used as input to a hydrology model to examine future changes in water availability or changes in floods.

Climate change projections require information about future emissions or concentrations of greenhouse gases, aerosols and other climate drivers. Recently, the Coupled Model Inter-comparison Project Phase 5 (CMIP5) generated new representative concentration pathways (RCPs), which represent scenarios of trajectories for greenhouse gas emissions (Moss et al., 2010; Knutti and Sedláček, 2012). These new generations of RCPs are used in the IPCC Fifth assessment report and expected to be the basis for climate change impact studies over the coming few decades (Ramirez-Villegas et al., 2013). The four Rcps, Rcp2.6, Rcp4.5, Rcp 6, and Rc8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m², respectively).

Emission scenarios/Representative concentration pathways: Plausible representation of the future development of emissions of greenhouse gas concentrations based on coherent and internally consistent set of assumptions about driving forces (such as demographic and socioeconomic development, technological change) and their likely relationships. In addition RCPs are referred to as pathways in order to emphasize that their primary purpose is to provide time-dependent projections of atmospheric greenhouse gas (GHGs) concentrations (Bjørnaes, 2015).

2.2 Agro-ecological Zones and Seasons in Ethiopia

Agro- ecological zones (AEZs) are geographical areas exhibiting similar climatic conditions that determine their ability to support rainfed agriculture. Agro-ecological zonation in Ethiopia has two facets namely the traditional and the elaborated agro-ecological zones. The most commonly used classification systems are the traditional (Deressa, .etal.2010). The traditional agro ecological zones developed by MOA are as follows based on elevations and temperature. An area below 500 m a.s.l is referred to as Berha and has an average annual temperature of above 27.5 degree Celsius with annual rainfall about less than 200 millimeters. Maize is largely grown in this zone .Kolla - is 500- 1500 meters in elevation and has an average annual temperature of about 20-27.5 degree Celsius with annual rainfall about 200-800millimetres. The Danakil Depression (Danakil Desert) is about 125 meters below sea level and the hottest region in Ethiopia where the temperature climbs up to 50 degree Celsius. Predominant crops are sorghum, finger millet, sesame, cowpeas, ground nuts etc.

Woina dega - includes the highlands areas of 1500 - 2300 meters in elevation has an average annual temperature of 17.5-20 degree Celsius with annual rainfall between 800 and 1200 millimeters. The major crops grown include wheat, teff, barley, maize, sorghum, chickpeas, haricot beans etc. Dega - is 2300- 3200 meters in elevation with an average annual temperature of about 11.5-17.5 degree Celsius with annual rainfall between 900 and 1200 millimeters. Predominant crops include barley, wheat, highland oilseeds, and highland pulses while areas' ranging from 3200-3700 m a.s.l. are referred to as wurch and has an average annual temperature of less than 11.5 degree Celsius with annual rainfall between 1200 and 2200 millimeters. Barley is the common crop growing.

2.3. Ethiopian Seasonal climatic characteristics

In Ethiopia there are three seasons, based on Climatological means of rainfall and temperature. These seasons are locally known as Bega, Belg and Kiremt (DegefuW., 1987; Gissila et al, 2004). These seasons determine the seasonal agricultural activities, such as land preparation, planting, weeding and harvesting by farmers. Kiremt(June-September) is the main rainy season in Ethiopia. There are various regional and global weather systems that affect the Kiremt season. These systems include the Inter Tropical Convergence Zone (ITCZ), the Maskaran High Pressure in the Southern Indian Ocean, the Helena High Pressure Zone in the Atlantic, the Congo air Boundary, the Monsoon depression and Monsoon trough, the Monsoon Clusters and the Tropical Easterly Jet (kassahun, 1999). The intensity and fluctuation of the rain-producing systems during the Kiremt season influence the amount and distribution of rainfall in Ethiopia (Babu, 1999b).

Kiremt rainfall is very important in Ethiopia. Most of the food is planted during this season. Drought during Kiremt may lead to food insecurity and starvation. With the exception of south and south eastern Ethiopia, most parts of the country receive 60 percent-90 percent of their rainfall during the Kiremt season (Babu, 1999a). The Bega season occurs between October-January. Bega is the dry, windy and sunny season in most highlands of Ethiopia. The causes of this dry season are the Sahara and Siberian High Pressures that send dry and cold winds to Ethiopia during the northern winter (kassahun, 1999). During the Bega, most of highlands of Ethiopia are sunny during the day and cold during the night and morning, which includes frost in

December and January. Farmers harvest their Meher crops during this dry period. The precipitation during the Bega season (October –January) is generally very low in most of the grain-producing parts of Ethiopia. However, the south and southeast of Ethiopia, which receives its second important seasonal rainfall in this period (NMSA, 1996). Belg season it is a short rainy season extends from February to May. This season has a great impact for belg benefiting areas. In addition it is important for land preparation and sowing of long cycle crops such as sorghum and maize. In some areas, the belg rainfall may produce up-to fifty per-cent of local food. The belg season is influenced by the tropical surface air masses in the Indian and Arabian anticyclones.

2.4 .Seasonal rainfall characteristics

2.4.1 Onset of rainy season

The onset of rainy season is characterized as the date when 20 mm or more rainfall is accumulated over three consecutive rainy days with no dry spell length greater than 7 days in the next 30 days as used in(Getaneh M.,2015;Taye et al.,2013; Hadigu et al .,2013;Ayalew et al.,2012).A study by Ayalew et al.,(2012) reported that 136 Day Of the Year(DOY) and 154 Day Of the Year (DOY) as median onset date of kiremt rainfall at Debre-Tabour and Gondar weather stations, respectively. In line with this Taye et al., (2013) found mean onset dates of 153 DOY, 151DOY, 151 DOY and 132 DOY at Bahir-Dar, Motta, Yetmetn and Debre Markos weather stations, respectively.

2.4.2. End of rainy season

End date of rainy season is defined differently by different researchers Segele and Lamb (2005), defined end date of rainy season as the first day when a dry-spell ($<0.1\text{mm}$ rainfall per day) of at least 20 days duration occur after the onset. Tesfaye and Walker (2004) defined end date as the date when the soil water balance becomes zero after first of September. The same definition was used by Mamo(2005);Taye et al.(2012); Ayalew et al.(2012);Hadigu et al.(2013) and Getaneh(2015).In Ethiopia, reports show varying end date of kiremt season. For example Ayalew et al. (2012) reported that 275 Day of the Year (DOY) and 282 Day of the Year(DOY) as the median end date of kiremt season at Debre-Tabor and Gondar weather stations, respectively for the period 1979-2008 whereas, Taye et al.(2012) found mean end date of

302Day of the Year(DOY), 304 DOY, 292 DOY and 302 DOY at Bahir Dar, Motta, Yetmen and Debre-Markos, respectively for the period of 1979-2008.

2.4.3 Length of the growing period

Length of rainy season is defined as the difference between onset date and end date (Getaneh, 2015; Hadigu et al., 2014; Kassie et al., 2014; Segele and Lamb 2005). According to Taye et al.(2013) on average the kiremt rainy season has length of 149 DOY,153 DOY,142 DOY,158 DOY and 185 DOY days at Bahir-Dar, Motta, Yetmen, Debre-Markos and Dangla weather stations, respectively in the north western Ethiopia. In another study Hadigu et al. (2013), reported that the average length of kiremt growing period in northern, Ethiopia varies from 66 to 85 days at Mekelle, Alamata and Edagahamus weather stations.

2.4.4 Number of rainy and dry days

A day is considered rainy if it accumulates 1 mm or more rainfall and the opposite is true for dry day. Different literatures report different threshold level of precipitation to describe a day as rainy. For instance, Love et al. (2008) described a day as rainy when more than 0.85 mm precipitation is accumulated. In other study, Stern et al. (2003) suggested a threshold of 4.95mm to define a day as rainy, whereas Tesfye and walker (2004), Mesay (2006) and Mekasha et al., (2014) defined rainy day as a day when a threshold of 1 mm of rainfall and above is accumulated in a day. The NMSA (1996) uses threshold of $>0.1\text{mm}$ of rainfall accumulated in a day to define a rainy day. On the other hand, a day is defined dry when less than a prescribed threshold level or no precipitation is recorded (Mesay, 2006; Love et al., 2008; Mekasha et al., 2014).A study by Hadigu et al. (2014) reported that number of kiremt rainy days of 50 days, 66 days and 61 days at Adigudum, Alamata and Mekelle weather stations, respectively in the Tigray region of northern Ethiopia. In a similar study Getaneh,(2015) found mean number of kiremt rainy days of 56 days, 51 days, 65 days and 57 days at Kombolcha, Kobo, Lalibela and Sirinka weather stations respectively in the north east Amhara region. With regard to the number of dry days, Degefu,(2014) revealed the number of dry days in a year vary from 236 days at Jinka to 279 days at Keyafer with trends being significantly increasing by 2.9 days/year at Sawla, and conversely significantly decreasing at Welayta-Sodo. In a similar study, Getaneh (2015) observed kiremt dry days of 66 days, 71 days, 57days and 64days at Kombolcha, Kobo, Lalibela and Sirinka weather stations respectively in the north east Amhara region.

2.4.5 Probability of dry spell length

Dry spell length is the maximum number of consecutive dry days with rainfall less than 1 mm per day exceeding 5, 7, 10, and 15 (Tesfaye and Walker, 2004). The same definition was used by Mesay (2006) to determine the dry days in rainy season found mean dry spell length of up to 28 days in the north western, northern and eastern parts of Ethiopia during Belg season. On the other hand a study by Hadigu et al. (2013), found dry spells of 21 days at Mekele, 26 days at Alemata and Edamame during the Kiremt season. In another study, Seleshi (2006) reported that dry spell length of 20.3 days at Mekele in the northern Ethiopia and 16.2 days at Jijiga in the eastern Ethiopia.

2.5. Observed climate variability and trend in Ethiopia

Both instrumental and proxy records have shown significant variations in the spatial and temporal patterns of climate in Ethiopia (Alebachew, 2011). The mean annual rainfall over the country (Ethiopia) ranges from about 2000 mm over some pocket areas in Southwest to about less than 100 mm over the Afar lowlands in the Northeast (Degufu, 1987; NMSA, 1996; Mekonnen, 1998). Over the last 50 years alone, the northern half, the central part and the Southwestern region of the country have experienced both dry and wet spells (NMSA, 1996).

According to the NMA (2007) average annual rainfall trends remained more or less constant between 1951 and 2006, whereas seasonal rainfall exhibited high variability. In another study by Senait et al., (2010) obtained there is considerable decline in rainfall from March-September in north and southeast and southwestern parts of Ethiopia after 1997. In particular, rainfall amounts have significantly decreased during the belg season in the east and southeast parts of Ethiopia. Additionally in Ethiopia, as per Misgina and Simhadri (2015a) kiremt rainfall in lowlands increased significantly by a factor of 106mm/decade, whereas highlands experienced non-significant change. Similarly Bewket and Conway, (2007), found that annual and kiremt rainfall showed significant increasing trend at Dessie and Labella whereas significant decreasing trend was observed at Debre Tabor for the study period of 1975-2003.

Recent studies by Fazzini et al. (2015) revealed that in Ethiopia average temperatures vary from less than 4 °C in mountain peaks to 32 °C in depressions.

According to Mc Sweeney (2008) have confirmed the temperature increase has been most rapid from July to September (0.32°C per decade) and the average number of hot days per year has increased by 73 (an additional 20% of days) and the number of hot nights has increased by 137 (an additional 37.5% of nights) between 1960 and 2006 over Ethiopia. Over the same period, the average number of cold days and nights per year decreased by 21 (5.8% of days) and 41 (11.2% of nights), respectively. These reductions have mainly occurred in the months of September to November during the years 1960-2006. An increasing trend in annual maximum temperature by 0.44°C whereas minimum temperature decreased by -0.12°C per year at Butajira station (Kassie et al., 2014).

2.6 Projected climate variability and change in Ethiopia

All models predicting future climate change scenario in Ethiopia arrive at similar conclusion in the sense that temperature would increase over a period of time. However, they give conflicting results concerning the predicted level of precipitation- constant, decreasing and increasing level of projected precipitation is generated using different models.

Like in most other parts of Africa, human-induced greenhouse gas emissions would bring further changes to Ethiopia's climate over the next century (Conway, 2011). Although the level of change and associated impacts depend on the extent of emission scenarios and the climatic models used to predict the future scenarios, In Ethiopia, a study conducted by Arndt et al. (2011) showed that Kiremt seasons rainfall is decreasing by 20% by 2080s. Similar study conducted by Ayalew et al. (2012) indicated that by 2050s and 2080s the amount of annual rainfall and number of rainy days will decrease in the Amhara National Regional State, Ethiopia. Moreover, future projection of rainfall suggests a forward shifting for Kiremt season (Hadigu et al., 2014). Climatic change is also expected to alter agriculturally relevant rainfall events, bearing profound effects on the livelihood of the farming communities (Lane and Jarvis, 2007; Cooper et al., 2009; Sarr, B. 2012). Therefore, assessing the variability and expected future changes of rainfall is essential for planning and designing appropriate climate change adaptation strategies (Thornton P. K., 2009; Belay Kassie, 2014). More importantly, assessing climate change at local level on the basis of climate extremes is essential to take advantage of changes that may lead to increased crop productivity and to buffer situations where increased stresses are likely (Thornton P. K., 2009). This, however, depends on the availability of future climate data at

local scales. On the other hand Conway (2011) indicate that the annual temperature of Ethiopia will increase by 2.2°C in 2050s while NMA(2007) reported that the annual temperature in Ethiopia is expected to increase in the range of 2.7°C to 3.4°C by the 2080s compared to the 1961-1990 base period. Climate model projections under the SRES A2 and B1 scenarios over Ethiopia show warming in all four seasons across the country, which may cause a higher frequency of heat waves as well as higher rates of evaporation (Conway, 2011).

Mean annual temperature will increase in the range of 0.9 °C to 1.1°C by 2030, in the range of 1.7°C to 2.1°C by 2050 and in the range of 2.7°C to 3.4°C by 2080 over Ethiopia for the IPCC midrange emission scenario compared to the 1961-1990 normal. Moreover, it states that a small increase in precipitation can be expected (NMA, 2007).

2.7 Climate Variability and Crop production in Ethiopia

Climate variability plays a great role in agricultural production having a direct impact from the start of land preparation to the final harvest (Akinseye et al., 2013; Mesike and Esekhade, 2014). According to Kirimi (2013) climate change and climate variability affect the productivity of agricultural ecosystems. Temperature and moisture are the two most influential climatic factors that determine spatial distribution growth and productivity of crops. According to Getaneh (2015), the impacts of rainfall on crop production in Ethiopia are closely related to its variability and occurrence of dry/wet spells during the crop growing periods.

Crop yield varies from season to season owing to variation in climate during the growing seasons(Bewket,2009;Ayalew et al.2012;Hadigu,2013).A study by Bewket(2016) showed that among cereals grown in the central highlands of Ethiopia Sorghum and wheat productions shows high year-to-year variations due the effect of local climate variability . Temperature extremes beyond the optimal range causes stress, injuries and productivity loss to crops. Studies suggested that a 1°C increase in temperature above optimum (15-20°C) reduces wheat yield by 10% (Brown, 2009) and studies confirmed that wheat is negatively affected by future projected climate compared to other crops in East Africa (Liu et al. 2008).

According to Jones and Thornton. (2013) the timing of heat stress in relation to crop development and the conditions under which it is grown determines extent of productivity loss. Maximum daytime temperatures accelerate crop maturity, resulting in reduced grain filling,

while higher minimum nighttime temperatures increase respiration losses. Zhang et al. (2010) report that rainfall and temperature have opposite effects on yield variability of maize and that rice production is highly correlated with the amount of rainfall from June to September (Selvaraju, 2003; KrishnaKumar et al., 2004). High night temperatures are commonly associated with increased respiration rates, leading to a decline in yield (Mohammed & Tarpley, 2009). High day temperature (32-36°C) has a significant negative effect on rice grain yield (Peng et al., 2004; Nagarajan et al., 2010; Welch et al., 2010).

Increased temperature leads to increased evapotranspiration and affects water availability, which is very important in the process of photosynthesis (Dawyer et al., 2006). In general, high temperature affects the chloroplasts where photosynthesis takes place through generation of reactive oxygen species (Kreslavski et al., 2007). Water shortage and heat stress are two of the most important environmental factors limiting crop growth, development, and yield (Prasad & Staggenborg, 2008). Warming trends are responsible for the suppression of global agricultural productivity (FAO, 2009). Low temperatures also affect crops by reducing their metabolic reactions (Sage & Kubien, 2007).

Variability and changes in these key elements cause significant effect on basic aspects of crop production. Similarly Parry et al., (2004) for instance, reported that cereal yields in East Africa will be declined by 5-20% by 2080s and NMA (2001) reported a decrease in wheat yield of 24-33% in Ethiopia by 2080s. According to Lobell and Field (2007) a 4°C rise in temperature will result in a 15% decrease in wheat production in low latitudes and east Africa experienced 10–13%, 16–20%, and 17–24% wheat yield decrease by the end of the 21st century under B1, A1B and A2 storylines, respectively. On the other hand Knox et al. (2012) reported that 15% sorghum yield reduction in the African continent by the 2050s.

Rowhani et al. (2011) specified that 20% increase in intra seasonal precipitation variability reduces agricultural yields by 4.2%, 7.2%, and 7.6%, respectively, for maize, sorghum, and rice, which are the major food crops in Tanzania. Consequently, they projected that by 2050 climate change and variability will affect crop yields in Tanzania by 3.6%, 8.9%, and 28.6% for maize, sorghum, and rice, respectively.

3. MATERIALS AND METHODS

3.1. Description of the study area

3.1.1. Geographical location

The study was conducted in Waghemra Zone which is one of the 11 administrative zones in Amhara National Regional State (ANRS), Ethiopia. It is located in between 12.26° - 13.29° N latitude, and 38.33° - 39.32 ° E longitudes with an area of about 9,039.04 km². In addition the area is bordered on the south by North Wollo, on the southwest by South Gondar, on the west by North Gondar, on the north and east by the Tigray Region (figure 3.1).

3.1.2. Climate Characteristics of the study area

The study area is characterized by monomodal (one peak rainfall) rainfall pattern and much of the rainfall is concentrated in the kiremt season (June-September). It receives a mean annual rainfall ranging from about 512.9mm at Tisiska to 876.2mm at Amdework (current study) and areal mean annual rainfall is 637.3mm. The mean kiremt, belg and bega rainfall of the study area is about 547.2, 68.2 and 17.5mm respectively. The mean annual maximum and minimum temperature are 26.3°C and 12.3°C (1986 - 2016) respectively. Likewise the mean temperature in the study area ranges from 17.7°C to 23°C with annual average temperature of 19.3°C (Table 3.1).

In general the study area has a semi-arid climatic condition. Based on the traditional classification the study area lies from kola to dega agro-ecological zones. More specifically Tisiska and Sahla district categorized under kola, Sekota and Abergele district grouped under woina dega while Amdework and Asketema district put under dega agro-ecological zones.

In the study area crop production mainly rain-fed cereal based production system and the most common crops growing in the area is wheat and sorghum. Sorghum and maize are long-cycle and warm weather cereals while wheat, barley, and tef are short-cycle cool weather cereals (CSA, 2014).

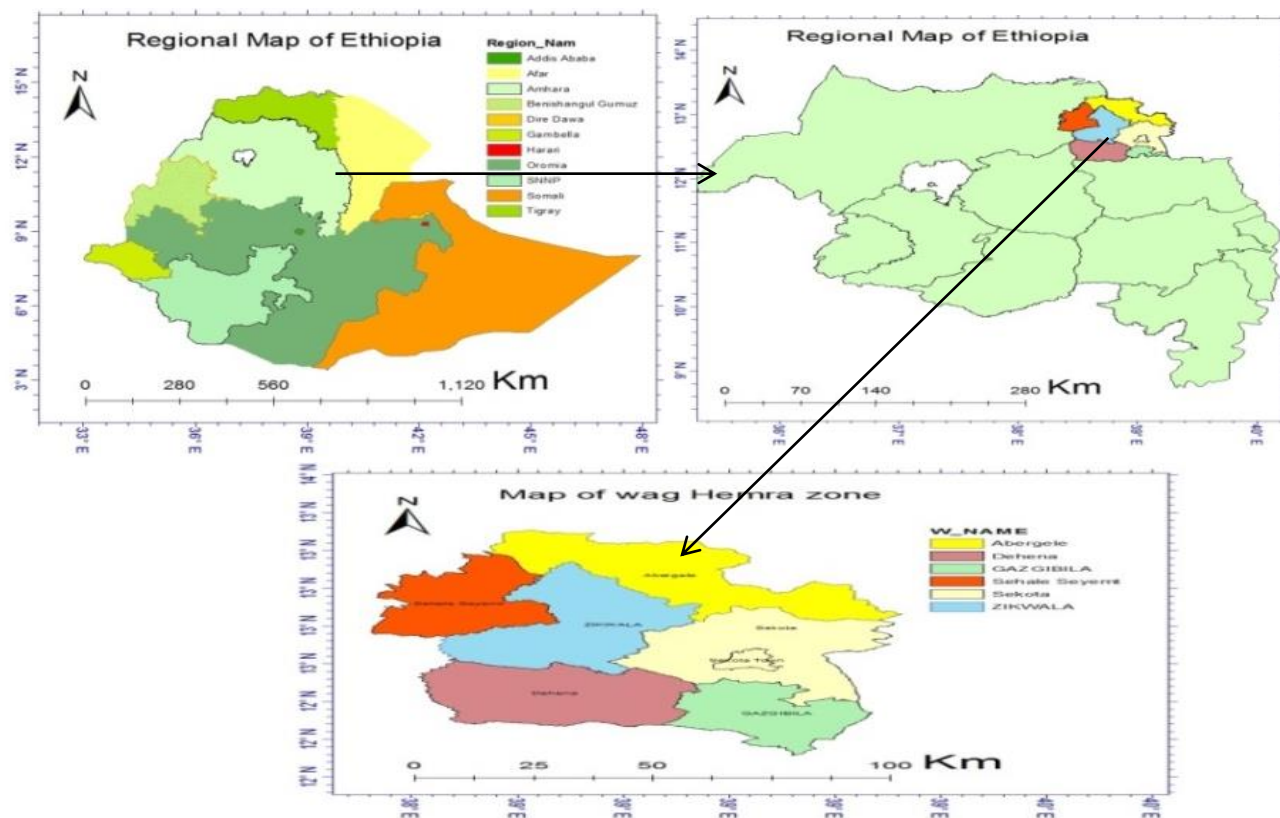


Figure 3.1. .Location map of study area

Table 3.1 .Geographical locations and climate characteristics of six weather stations for the study area

Station name	Latitude (north)	Longitude (east)	Altitude (meter)	Mean annual rainfall	Mean annual temperature
Amdework	12.4°	38.7°	2561	876.2	16.6
Asketema	12.4°	39°	2435	589.3	17.5
Sahla	12.9°	38.5°	1266	512.9	21.1
Sekota	12.6°	39.6°	2258	573.7	19.3
Tisiska	12.8°	38.8°	1469	754.5	21.0
Abergele	13.1°	38.9°	1571	516.94	20.5

3.2 Data source for the selected stations

3.2.1 Observed climate data

Long term daily rainfalls, maximum and minimum temperatures data of six weather stations (Amdework, Asketema, Sahla, Sekota, Tisiska and Abergele) were collected from the National Meteorology Agency (NMA) of Ethiopia and from kombolcha meteorological directorate for the period 1986 - 2016.

3.2.2 Future climate data

Climate change scenarios for mid -century (2040 - 2069) and end-century (2070 - 2099) periods were generated using 20GCMs from CMIP5 (Table 3.2) for the two representative concentration pathways (Rcp4.5 and Rcp8.5). Site specific climate change scenario data for the study stations were downscaled Agricultural Model Inter-comparison and Improvement Project (AgMIP) climate scenario generation scripts (R studio/R-software) for 20-global climate models (20-GCM's) from the ready-made data sets for east Africa region (Asseng et al., 2013).

Future climate time series were constructed using the delta change method (Fowler, 2007). The delta change method involves perturbing observed climate time series by mean changes (differences or ratios of changes) simulated with GCMs. A delta method was used for each specific month for rainfall and temperature, to consider seasonal differences in climate change. For temperature, the same delta was applied to minimum and maximum temperatures. Changes in rainfall and temperature for the 2080s relative to the current baseline period (1986 - 2016) have then been determined based on outputs from the GCMs and the observed climate data of the meteorological stations used for this analysis.

Table 3.2. Coupled Model Inter comparison Project phase 5 (CMIP5) general circulation models considered in this study

Climate Model	Climate modeling group	Country	Lat	Long	Res
ACCESS1.0	Commonwealth Scientific and Industrial Research Organization/Bureau of Meteorology (CSIRO-BOM)	Australia	1.87	1.25	MR
BCC-CSM1.1	Beijing Climate Centre, China Meteorological Administration	China	2.81	2.79	LR
BNU-ESM	College of Global Change and Earth System Science, Beijing Normal University	China	2.81	2.79	LR
CCSM4	Community Climate System Model, Climate and Global Dynamics Division/ National Centre for Atmospheric Research	USA			
CESM1-BGC	Community Earth System Model, Climate and Global Dynamics Division/National Centre for Atmospheric Research	USA			
CSIRO-Mk3.6	Commonwealth Scientific and Industrial Research Organization/ Queensland Climate Change Centre of Excellence (QCCCE)	Australia	1.87	1.87	MR
CanESM2	Canadian Centre for Climate Modeling and Analysis	Canada	2.81	2.79	LR
GFDL-ESM2G	Geophysical Fluid Dynamics Laboratory	US-NJ	2.5	2	LR
GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory	US-NJ	2.5	2.	LR
HadGEM2-CC	Met Office Hadley Centre	UK-Exeter	1.87	1.25	MR
HadGEM2-ES	Met Office Hadley Centre	UK-Exeter	1.75	1.25	MR
IPSL-CM5A-LR	Institute Pierre-Simon Laplace	France	3.75	1.89	LR
IPSL-CM5A-MR	Institute Pierre-Simon Laplace	France	2.5	1.26	LR
MIROC-ESM	Atmosphere and Ocean Research Institute (University of Tokyo), National Institute for Environmental Studies and Japan Agency for Marine-Earth Science and Technology	Japan	2.81	2.79	LR
MIROC5	Atmosphere and Ocean Research Institute (University of Tokyo), National Institute for Environmental Studies and Japan Agency for Marine-Earth Science and Technology	Japan	1.4	1.4	HR
MPI-ESM-LR	Max Planck Institute for Meteorology (MPI-M)	Germany	1.87	1.87	MR
MPI-ESM-MR	Max Planck Institute for Meteorology (MPI-M)	Germany	1.87	1.87	MR
MRI-CGM3	Meteorological Research Institute	Japan	1.12	1.12	HR
Nor-ESM1-M	Norwegian climate center	Norway	2.5	1.89	LR
INM-CM4	Institute for numerical mathematics	Russian	2	1.5	MR

Lat=latitude, long=longitude, Res=resolution, LR=low resolution, MR=medium resolution, HR=high resolution

3.2.3 Data quality control assessment

The daily time series from each station and for each year were plotted to identify obvious outliers, which were removed from the data series. Outliers were detected using the Turkey fence approach (Tukey, 1977). The rules of this approach are that inner fences are located at a distance 1.5 times interquartile range below the lower and above the upper quartiles and outer fences are located a distance 3 times the interquartile range below the lower and above the upper quartiles. Values outside the turkey fences are considered as outliers. Negative daily rainfall records were also removed and maximum and minimum temperature values were set to missing values if the daily maximum value was less than the daily minimum value. The data series was also examined for homogeneity and no heterogeneity was detected. Missing data in time series were filled with data from neighboring stations using statistical regression techniques as described in detail in (Allen, 1998b) and applied in various studies (Seleshi,2004;Vergni and Todisco,2011). Additionally the missing data were filled with gridded data .The gridded data are constructed data series based on records of gauge stations and meteorological satellite observations. This data is very useful in view of that weather stations are limited in number and unevenly distributed and a short period of observation.

3.2.4 Crop yield data

The crop yield data (wheat and sorghum) were obtained from the Central Statistics Agency (CSA) and Waghemra Zone agriculture office. The data for the study area covers for the period 2007 - 2016 due to lack of available crop yield only 10 years data were collected for analysis.

The production data is generated from a sample survey of smallholder farmers with area cultivation in hectares and total production in Quintals (a Quintal is 100 kg).

3.3 Data analysis

The temporal variability and occurrence of various rainfall and temperature indices were evaluated at selected weather stations based on the analysis of a set of indicators defining variation and extreme conditions, following (Trnka and Vergni, 2011, Stern R.D., 1982).

The rainfall indices include values of accumulated rainfall (monthly, annual and seasonal), number of rainy and dry days, number of heavy rainfall, mean daily rainfall intensity, precipitation concentration index (PCI) , normalized rainfall anomaly , start of the growing

season (SOS), end of the growing season (EOS), length of growing season (LGS), and dry spell probability. The temperature indices were mean seasonal and annual maximum, mean seasonal and annual minimum, maximum of the maximum, maximum of the minimum, minimum of the maximum, minimum of the minimum, number of warm days, number of warm nights, number of cool days and number of cool nights. Data analyses was under taken using INSTAT, software, Gen stat software, R-software, XLSTAT software and excel spreadsheet

Trends were assessed using Mann-Kendall trend test (Mann, 1945; Kendall, 1975) and Sen's slope estimator (Sen, 1968). The Mann-Kendall test is a non-parametric approach, widely applied in various trend detection studies (Alexandar and Kizza, 2009, Karaburun, 2011). Statistical analyses and other computations were performed with INSTATv3.37 statistical software (Stern R., 2006). Trends analyses were carried out by XLSTAT2014.

3.3.1 Analysis of rainfall and temperature variability

The temporal rainfall variability for representative meteorological stations was determined by calculating the coefficient of variation (CV) as the ratio of the standard deviation to the mean rainfall in a given period (equation 3.0), when expressed as a percentage) Hare (1983), Standardized rainfall anomaly (SRA), Precipitation Concentration Index De Lui's et al. (1999) were used to evaluate the variability of rainfall in the study area (equation 3.1&3.2). The coefficient of variation statistics were utilized to test the level of mean variation of annual and seasonal rainfall amount and calculated by using the following formula

$$cv = \frac{SD}{\bar{X}} * 100 \text{ where } \bar{X} = \frac{\sum xi}{N} \text{ and } SD = \frac{\sqrt{(\sum (xi - \bar{X})^2)}}{N-1} \quad (3.0)$$

Where CV= Coefficient of variation, SD=standard deviation of the time series and $\bar{x}$ = mean of the time series, N =number of observation. When $CV < 20\%$ it is less variable, CV from 20% to 30% is moderately variable, $CV > 30\%$ is highly variable, $CV > 40\%$ very high and $CV > 70\%$ indicate extremely high inter-annual variability of rainfall. Areas with $CV > 30\%$ are said to be vulnerable to drought. The precipitation concentration index used for characterizing the monthly rainfall distribution is given by Oliver (1980)

$$\text{Annual PCI} = \frac{(\sum p_i^2)}{(\sum p_i)^2} * 100 \quad (3.1)$$

$$\text{Seasonal PCI} = \frac{(\sum p_i^2)}{(\sum p_i)^2} * 25 \quad (3.2)$$

Where, P_i is the rainfall amount of the i^{th} month. PCI values of less than 10 indicate uniform monthly rainfall distribution in the year, PCI 11-15 indicates moderate precipitation concentration, PCI 16- 20 indicates irregular distribution. PCI values above 20 correspond to substantial monthly variability (a strong irregularity) in rainfall amounts. Inter-annual variability was evaluated using standardized anomalies for rainfall with respect to the long-term normal conditions for a specific time scale. According to Agnew and Chappell (1999) the standardized anomalies of rain fall was calculated as follows (equation 3.3).

$$\text{SRA} = \frac{P_t - P_m}{\sigma} \quad (3.3)$$

Where SRA = standardized rainfall anomaly, P_t = annual rainfall in year t , P_m = is long-term mean annual rainfall over a period of observation and σ = standard deviation of annual rainfall over the period of observation. Positive normalized rainfall anomalies indicate greater than long-term mean rainfall, while negative anomalies indicate less than the mean rainfall.

Table 3.3. Classification of the dryness and wetness of degree in accordance with SPI values definitions

Category of dryness/wetness	Standardized Rainfall Anomaly(SRA)
Extremely dry	≤ -1.65
Severely dry	$-1.28 > \text{SRA} > -1.65$
Moderately dry	$-0.84 > \text{SRA} > -1.28$
Near normal	$\text{SRA} > -0.84$
Moderately wet	$0.84 < \text{SRA} < 1.28$
Severely wet	$1.28 < \text{SRA} < 1.65$
Extremely wet	$\text{SRA} \geq 1.65$

Moreover, the monthly rainfall series of all the stations were used to calculate an areal average rainfall for the region (Zones) as follows (Nicholson, 1985): $R_j = \frac{\sum_{k=1}^j X_{ij}}{I_j}$ (3.4)

Where R_j is a real integrated rainfall for year j ; X_{ij} is rainfall at station i for year j and I_j is the number of stations available for year j . Variability and trend in the areal rainfall is also examined using the same methods.

3.3.2 Analyzing the growing season and rainfall characteristics

Onset of rainy season

The onset of rainy season was determined as the date when 20 mm or more rainfall accumulated over three consecutive rainy days after a starting date (1st of June for the Kiremt season and 1st of February for the Belg season) with no dry spell length greater than 7 days in the next 30 days as used in (Abebe, 2006; Tesfaye K. and Walker, 2004). INSTAT 3.37 software is used to compute start date of growing season for each studied stations.

End of growing season

On the other hand, the end of growing season was mainly dictated by the stored soil water and its availability to the crop after the rain stops. In this study, the end of the rainy season was defined as any day after 1st of September for Kiremt and 1st of May for Belg seasons when the soil water balance reaches zero (Stern *et. al*, 1982). Since the dominant soil for all locations studied is Vertisols with high clay content (>50%), a 100 mm/meter of the plant available soil water and site specific daily reference evapotranspiration (ET_o) values were considered. The same method was used by several authors to determine end date of growing season (Mamo, 2005; Mesay, 2006; Taye et al., 2013; Feyera, 2015). In addition to Soil water holding capacity for each studied stations, site specific daily Evapotranspiration (ET_o) is computed enable to compute EOS for each station using INSTAT v. 3.37 software.

Length of growing period

Length of Kiremt and Belg growing season was determined as the difference between the end and onset of rainy season (Mamo, 2005; Mesay, 2006; Liben, 2013; Hadigu et al., 2014)

Number of rainy and dry days

Even though the smallest recorded amount of rainfall is 0.1 mm, a threshold value of 1mm was used to define days as wet or dry because 0.1mm of rainfall value almost has no effect on growth of crops (Robel et al.,2013). Thus, in the current study, number of rainy and dry days was determined by counting all days with rainfall $\geq 1.0\text{mm}$ as rainy and those days with $< 1.0\text{mm}$ as dry days respectively as outlined by (NMSA, 2001). Different researchers used the same definition (Segele and Lamb 2005; Mesay2006; Hadigu et al., 2013).

Likewise, number of heavy precipitation day was determined by counting the annual number of days in the season having precipitation greater or equal to twenty mm, and the simple daily intensity index was computed as total precipitation of rainy days in the season divided by the number of rainy days with precipitation $\geq 1\text{mm}$ as out lined in (Mekasha A., 2014; Degefu M. a., 2014) .

Dry spell probability

The dry spell probabilities were determined as consecutive number of days with rainfall less than 1 mm per day exceeding 5, 7, 10 and 15 consecutive days. Dry spell length was analyzed by Markov Chain analysis Stern &cooper (2011) and using INSTATv3.37 software. The probability of dry spell lengths of 5, 7, 10 and 15 days during the growing season were determined from the Markov chain model to get an overview of dry spell risks during the crop growing period.

Trend Analysis

To estimate the sign and slope of long term mean annual and seasonal rainfall and temperature for the selected study sites, Mann-Kendall's trend test and Sen's slope estimation method were used.

Mann-Kendall'test

The Mann-Kendall's test was employed to detect trends of the temperature and precipitation of each site(equation 3.5) .Mann-Kendall's test is a non-parametric method, which is less sensitive to outliers and test for a trend in a time series without specifying whether the trend is linear or nonlinear (Partal, 2006; Yenigun, 2008). Many different study of time series data show that trend is either decreasing or increasing, both in case of temperature and precipitation.

The Mann-Kendall's test statistic is

$$\text{given as: } S = \sum_{i=1}^{N-1} (\sum_{j=i+1}^N \text{sgn}(x_j - x_i)) \quad (3.5)$$

Where x_j and x_i are the sequential precipitation or temperature values in months j and i ($j > i$) and N is the length of the time series. A positive S value indicates an increasing trend and a negative value indicates a decreasing trend in the data series.

The variance of S , for the situation where there may be ties (i.e., equal values) in the x values, is given by (equation 3.6)

$$\text{Var}(s) = \frac{1}{18} [N(N-1)(2N+5) - \sum_{i=1}^m t_i(t_i-1)(2t_i+5)] \quad (3.6)$$

Where, m is the number of tied groups in the data set and t_i is the number of data points in the i th tied group. For n larger than 10, the standard normal Z_{MK} test statistic is computed as follows (Partal and Kahya, 2006)

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{\text{var}(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{\text{var}(S)}} & S < 0 \end{cases} \quad (3.7)$$

The presence of a statistically significant trend is evaluated using the Z_{MK} value. In a two-sided test for trend, the null hypothesis H_0 should be accepted if $|Z_{MK}| < Z_{1-\alpha/2}$ at a given level of significance. $Z_{1-\alpha/2}$ is the critical value of Z_{MK} from the standard normal table. E.g. for 5% significance level, the value of $Z_{1-\alpha/2}$ is 1.96

Sen's Slope Estimator test;

The magnitude of trend is predicted by the Sen's estimator. The slope (T_i) of all data pair computed as (Sen, 1968). This test is applied in cases where the trend is assumed to be linear, depicting the Quantification of changes per unit time.

$$T_i = \frac{x_j - x_k}{j - k} \quad (3.8)$$

for $i = 1, 2 \dots N$ Where X_j and X_k are considered as data values of time j and k ($j > k$) correspondingly. The median of these N values of T_i is represented as Sen's estimator of slope which is given as

$$Q_i = \begin{cases} \frac{1}{2} (T_{\frac{N}{2}} + T_{\frac{N+2}{2}}) & \text{if } N \text{ is even} \\ T_{\frac{N+1}{2}} & , \text{if } N \text{ is odd} \end{cases} \quad (3.9)$$

Positive value of Q_i indicates an upward or increasing trend and a negative value indicates downward or decreasing trend in the time series

Correlation Analysis

Correlation and regressions techniques are important in showing the relationship between climatic parameters and crop production, and to identify the most predictor variable. Lemi 2005; Bewket, 2009; Tunde, 2011; Rowhani et al., 2011; Adamgbe and Ujoh 2013 and Akinseye et al. (2013) used the same methodology in their study of the relationship between climate variables and crop production. The Pearson correlation coefficient(r) was analyzing to evaluate the linear relationship between the climatic parameter (rainfall and temperature) and the crop yields (wheat and sorghum).

Correlation coefficient(r) value close to +1 indicates a strong positive correlation while correlation coefficient close to -1 indicates as a strong negative correlation and a correlation coefficient of 0 was interpreted as indicators of no correlation or association between climate variables and crop yield. The formula for computing Pearsonian correlation(r) (equation 3.10).

$$r = \frac{\sum xy - \sum x \sum y}{\sqrt{[n \sum x^2 - (\sum x)^2][n \sum y^2 - (\sum y)^2]}} \quad (3.10)$$

Where y is the observed yield, x is either rainfall or

Temperature value and n is number of observation

Multiple Regression Analysis

Multiple regression analysis was carried out in order to determine the relationship between the climatic variables (temperature and rainfall) and crop yields (equation 3.11).

The analysis described the effects of the two independent variables jointly on the yields of the crops. The dependent variables (response) are the yields of wheat and sorghum, while the independent variables (predictors or explanatory) are the annual and seasonal rainfall and mean

temperature. The multiple linear regression equations with only two independent variables as follows

$$\hat{y} = b_0 + b_1x_1 + b_2x_2 + \varepsilon_i \quad (3.11)$$

Where $\hat{y}$ the dependent variable (response/output), b_0 is the intercept, x_1 and x_2 are the independent variables (predictors), b_1 and b_2 are the coefficients of x_1 and x_2 respectively and ε_i is the error that has normal distribution with mean of zero.

The coefficients of independent variables (b_1 & b_2), intercept and the error are estimated as follows (equation 3.12).

$$b_1 = \frac{ryx_1 - r_{yx_2}rx_1x_2}{1 - (rx_1x_2)^2} * \frac{SY}{SX_1}, \quad b_2 = \frac{ryx_2 - r_{yx_1}rx_1x_2}{1 - (rx_1x_2)^2} * \frac{SY}{SX_2}, \quad b_0 = \bar{Y} - (b_1\bar{x_1} + b_2\bar{x_2}), \quad \varepsilon_i = y - \hat{y} \quad (3.12)$$

Model Validation and Statistical Evaluation

The comparison of simulated with observed yields allows the assessment of the model capacity to represent local crop systems. The following statistical error measurements were used for the evaluation and validation of the developed statistical regression models for the two crops (wheat and sorghum): The coefficient of determination (R^2), root mean square error (RMSE) and index of agreement or d-statistic were employed as statistical indicators to evaluate the performance of the model. The coefficient of determination (R^2) explained the proportion or fraction of the variation in the response variable that can be accounted for by the two predictors in the multiple regression models (Attah, 2013). The coefficient of determination (R^2) evaluated as follows (equation 3.9.1)

$$R^2 = \frac{(\sum(y_{ob} - \overline{y_{ob}}))^2 - (\sum(y_{sim} - \overline{y_{sim}}))^2}{\sum(y_{ob} - \overline{y_{ob}})^2} \quad (3.13)$$

where y_{ob} =observed yield, y_{sim} =simulated yield, $\overline{y_{ob}}$ =mean of observed yield, $\overline{y_{sim}}$ =mean of simulated yield

The range of R^2 is extends from 0 (unacceptable) to 1. If the simulation is accurate, R^2 is equal to 1. An efficiency of R^2 is equal to zero indicates that the model predictions are as accurate as the mean of the observed data (Krause, Boyle, & Base, 2005).

Root mean square error (RMSE) is a measure of the difference between actually observed values that is being modeled and the values predicted by a model. These individual differences are called residuals, and the RMSE serves to aggregate them in to a single measure of predictive power. Small values of RMSE considered as indicators for good performance of the regression model. The RMSE was computed using the following equation (equation 3.9.2):

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (y_{obi} - y_{simi})^2}{n}} \quad (3.14)$$

where n is number of observation, y_{obi} =observed yield for i^{th} measurement, y_{simi} =predicted yield for i^{th} measurement

On the other hand, d-statistic provides a single index of model performance that encompasses bias and variability. Small values of d is considered as good performance of the regression model (Yang & Seager, 2014) the d-statistic was computed as (equation 3.9.3)

$$D = 1 - \left[\frac{\sum (y_{sim} - y_{ob})^2}{\sum |((y_{sim} - \overline{y_{ob}}) + (\overline{y_{ob}} - y_{sim}))|^2} \right] \quad (3.15)$$

Where y_{ob} =observed yield, y_{sim} = simulated yield,

$\overline{y_{ob}}$ = mean of observed yield, $\overline{y_{sim}}$ = mean of simulated yield

Future climate scenario analysis

Projected changes in rainfall and temperature were analyzed based on 20 combinations of General Circulation Models (GCMs) and two emission scenarios, Rcp4.5 and Rcp8.5.

For the comparison purpose of the projected future change from base line period the percentage change of rainfall was calculating as follows (equation 3.9.4)

$$\text{Percentage change} = \frac{\text{projected rainfall} - \text{base line rainfall}}{\text{base line period rainfall}} * 100 \quad (3.16)$$

Where base line period=1986-2016

Future rainfall=2050s (2040 - 2069) and 2080s (2070 - 2099).

4. RESULTS AND DISCUSSIONS

Based on the objective of the research, the result and discussion are presented in tables and graphs as the observed historical (1986-2016) and the projected (2040 - 2069) and (2070 - 2099) climate variability and trends in terms of rainfall and temperature (maximum & minimum) as well as its effect on production of major crops grown in the Waghemra Zone of the Amhara National regional State of, Ethiopia.

4.1 Observed climate variability and trends

4.1.1 .Descriptive statistics of annual and seasonal rainfall

Annual rainfall variability

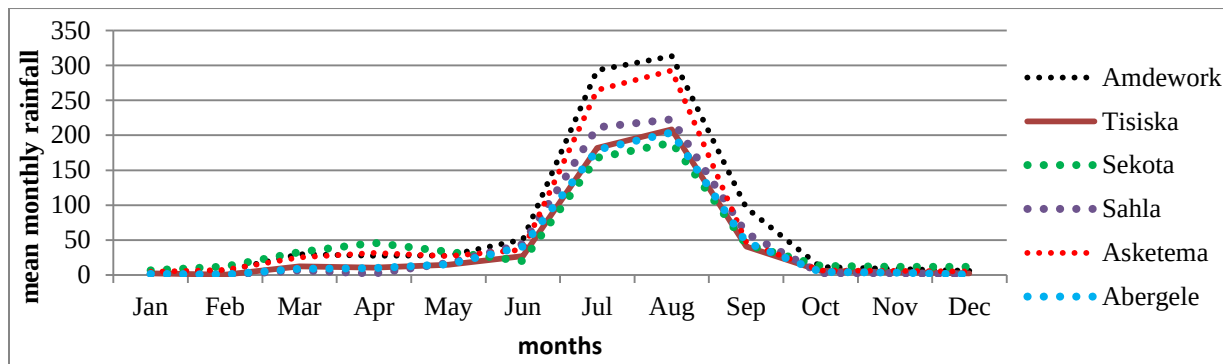
Table (4.1) shows that the descriptive statistics of annual rainfall

The annual rainfall amount ranged from 200.7mm at Tisiska to 1734.4mm at Amdework stations during the last 31 years (Table 4.1). Likewise the areal annual rainfall ranged from 391.7mm to 892.3mm with mean annual rainfall 637.3mm over the last 3 decades. This indicates a great variation in both station to station and year to year.

The coefficient of variation observed in the present study also ranged from 19.6% at Sahla to 36.7 at Asketema (Table 4.1). Based on Hare (1983) classification in equation (3.1) the result shows that less and high inter-annual variability of rainfall at Sahla and Asketema respectively.

In general the coefficient of variation revealed that high inter-annual variability of rainfall at Amdework($cv=32.1\%$), Tisiska(30.3%) and Asketema($cv=36.7\%$) in (Table 4.1). This implies that the annual rainfall was more unreliable and unpredictable in these areas. The overall predictability of these climatic elements (rainfall) is crucial for the day-to-day and medium term planning of farm operations. Moreover based on the scale defined in De Lu's et al. (1999) the analysis of precipitation concentration index (PCI) value revealed that all stations have greater than 20% (Table 4.1). This implies that rainfall pattern in the study area is not uniformly distributed. A similar result was also indicated in Bewket and Conway (2007) and Ayalew et al. (2012) rainfall in the Amhara region of Ethiopia is characterized by high to very high monthly concentration. Accordingly, the stations located at the lowland area (Tisiska and Sahla) recorded lower mean annual rainfall than station at the highland (Amdework & Asketema) and midland

(Sekota & Abergele). Crops are mainly grown in the highlands of the area which is characterized by sufficient precipitation. Any increase in the level of precipitation will generate significant damages on crop production in these parts of the region. This increase in precipitation will also entail flooding (common phenomenon in the rainy seasons) in the lowlands and thereby will reduce crop yields. Also Figure 4.1 indicates that the unimodal distribution of rainfall is allowed for the cultivation of Wheat and Sorghum once in a year containing one peak the highest peak in July and the August.



Figures 4.1. The mean monthly rainfall distribution at six stations in the study area 1986 - 2016

Table 4.1. Descriptive statistics for annual rainfall at selected stations for the period 1986-2016

Station	Min	Max	Mean	SD	CV (%)	PCI (%)
Amdework	358	1734.4	876.2	280.9	32.1	25.9
Sekota	267	845	589.3	156.2	26.5	20.5
Tisiska	200.7	756	512.9	155.2	30.3	30.2
Sahla	328	828	573.7	112.6	19.6	30.4
Asketema	356	1662	754.5	276.8	36.7	28.4
Abergele	323	928	516.94	126.18	24.4	29.2
Areal mean	391.7	892.3	637.3	184.6	28.9	27.4

Min =minimum value, Max= maximum value, SD=standard deviation, CV=coefficient of variation, PCI=precipitation concentration index

Kiremt rainfall variability

At the seasonal level, the kiremt (June-September) rainfall varies from 126mm at Sekota to 1654.3mm at Asketema Station (Table 4.2). The kiremt areal rainfall ranged from 270.8 to 845.9 mm with a mean of 547.2 mm and a standard deviation of about 188.8 and coefficient of

variation 34.5%. The kiremt rainfall contribution to the annual rain fall totals varies from 71.5% at Sekota to 93.8% at Sahla station during the past 3 decades (1986-2016).The result showed that main rainy season (kiremt rainfall) contributed largely to the annual rainfall totals in all stations .This is supported by Bewket and Conway 2007; Ayalew et al., 2012 in the Amhara regional State of Ethiopia, kiremt rainfall had contributed 55 to 85% to the annual rainfall totals.

The kiremt rainfall coefficient of variation ranged from 28.2% at Abergele to 47.2 at Asketema station (Table 4.2).In general the observed kiremt rainfall coefficient of variation in all stations revealed that highly variable (CV>30%) except at Abergele which was moderate variable. Considering the direct effect of kiremt rainfall on agricultural production, high variability could tremendously affect the livelihood of the farming community in the study area.

Rainfall pattern is unimodal in most stations which shows that the study area has one cropping season and the total cultivated land of the study area is cropping during the kiremt season (June-September).Moreover, based on the scale defined in Oliver's classification (1980) precipitation concentration index (PCI) value less than 10% indicate that low concentration. This implies that nearly the same amount of rainfall occurs in each month of the wet season.

Table 4.2.Descriptive statistics of kiremt seasonal (June-September) rainfall at the selected stations for the period 1986-2016

Station	Min	Max	Mean	SD	CV (%)	PCI (%)	CT (%)
Amdework	269	1600	753.7	279.4	37.1	8.6	86
Sekota	126	723.9	421.3	148.3	35.2	9.4	71.5
Tisiska	159	743	458.6	155.3	33.9	9.4	89.4
Sahla	314	807	538.3	114.5	35.2	8.6	93.8
Asketema	190	1654.3	640.1	302.2	47.2	9.7	84.8
Abergele	268	900	470.9	132.9	28.2	8.7	91.1
Areal mean	270.8	845.9	547.2	188.8	34.5	9.1	86.1

Min =minimum value, Max= maximum value, SD=standard deviation, CV=c oefficient of variation, PCI=precipitation concentration index, CT= contribution of kiremt rainfall to the annual (%)

Belg rainfall variability

On the other hand, Belg(February-May) mean rainfall amount was ranging from 26.5mm at Sahla to 124.4 mm at Sekota station (Table 4.3). The areal belg rainfall ranged from 5.5 to 185.2mm with a mean of 68.2mm and a standard deviation of about 52.6 and coefficient of variation 59.3%.Moreover, the contribution of Belg rainfall to the annual total rainfall varied from 4.6% at Sahla to 21.1% at Sekota stations in the study area. In line with this in the Amhara regional state of Ethiopia belg rainfall had contributed 8 to 24% to the annual rainfall totals (Bewket and Conway 2007; Ayalew et al., 2012). The result indicated that Belg rainfall variability for all stations were extremely high variable ($CV > 50\%$).This implies that the Belg rainfall was characterized by high variability according to the classifications given in Hare (1983). Therefore, based on Hare (1983) classification, the study area has been vulnerable to drought during belg season ($CV > 30\%$).Similarly, high Belg rainfall variability was also reported by Ayalew et al.,(2012) over the Amhara Region and Getaneh(2015) over North Eastern Amhara compared to the Kiremt and annual total rainfall. Various studies indicate that the amount and temporal distribution of rainfall is generally the most important determinant of inter-annual fluctuations in crop production in Ethiopia and has reported to have significant effects on the country's economy and food production for the last three decade (Araya and Stroosnijder, 2011; Conway and Schipper, 2011; Demeke et al., 2011). High climatic variability (e.g. low and variable distribution of rainfall) represents a delicate balance between agricultural production and food security.

The amount and distribution of rainfall affects many other aspects of agricultural production among smallholder farmers in SSA, namely farm sizes, crop enterprises, cropping calendars, incidence and growth of weeds, crop pests and diseases (Yengoh *et al.*, 2010). Rainfall variability from season to season greatly affects soil water availability to crops, and thus poses crop production risks. Variability in seasonal rainfall (i.e., the accumulated amount of rainfall from the planting to the harvest of a crop) is higher in the areas with smaller amount of rainfall. Generally, the seasonal rainfall variability was higher than the annual rainfall variability in Waghemra Zone.

Table 4.3. Descriptive statistics of Belg season (February-May) rain fall at six stations for the period 1986-2016

Station	Min	Max	Mean	SD	CV (%)	PCI (%)	CT (%)
Amdework	0	251	91.8	60.7	66.1	7.4	10.5
Sekota	24	325	124.4	86.3	69.4	7.2	21.1
Tisiska	0	174.8	39	39.9	102.3	8.1	7.6
Sahla	0	126	26.5	29.2	109.8	12.1	4.6
Asketema	0	253	92.2	65.9	71.5	7.2	12.2
Abergele	0	142	35.07	33.78	96.3	8.5	6.8
Areal mean	5.5	185.2	68.2	40.5	59.3	8.4	10.7

Min =minimum value, Max= maximum value, SD=standard deviation, CV=coefficient of variation, PCI=precipitation concentration index, CT= contribution

4.1.1.1. Rainfall anomaly

The result of standardized rainfall anomaly of rainfall data are given (figure 4.2)

The rainfall in the waghemra zone was characterized by sporadic fluctuation of wet and dry years in a periodic pattern. The annual rainfall anomaly showed negative anomalies ranging from 38.7% at Sekota to 54.8% at Amework stations during the study period. Similar study was also reported by Bewket and Convay(2007) during the period 1961–2003, the proportion of negative anomalies ranged from 39% at Debre Markos to 53% at Gondar of total number of observations.

As it can be seen from figure (4.2) a number of years recorded below the long term average rainfall .The deviation from the mean at Amdework, Asketema,Sahla,Sekota and Tisiska were 54.8%, 51.6%, 41.9%, 38.7% and 45.2% respectively . The persistence of negative anomalies for those stations indicated that the study area is characterized as dry. On the other hand the standardized anomalies of annual rainfall revealed that weak to strong positive departure from the mean rainfall at Amdework, Asketema, Sahla, Sekota and Tisiska were 45.2%, 48.4%, 58.1%, 61.3% and 54.8% respectively. The positive rainfall anomalies during this period indicated that the study area experienced wet conditions. Based on the SRA values Agnew and Chappel (1999) the study area experienced moderate to extreme dry in many of the years.

The standardized rainfall anomaly result showed that extreme dry in the years 1987, 1990 and 1991, 1993 and 2013 and 2014 at Amdework, Sekota, Sahla and Tisiska stations respectively. Similarly, severe dry were experienced at Asketema , Amdework, Sahla , Abergele, Sekota and Tisiska stations in the years 1987 and 1990, 1990 and 1991, 1992 and 1997, 2002, 2004 and 2015, 1987, 2009 and 2015 respectively. Moreover, the study area were experienced moderate dry in the years 1986, 1987, 1989, 1990, 1991, 1993, 2011, 2013, 2014 and 2015 of the study period. Similar study reported that North eastern Ethiopia was experienced to drought in the years of 1992, 1997, 2000, 2002, 2009 and 2011 (viste, 2012) .Conversely, of the observed 31 years extreme wet in the years 1994 and 1998, 1998, 2001 and 2003, 2004 at Abergele , Sahla, Amdework and Asketema stations respectively whereas years like 1994, 1996, 1999, 2000, 2001, 2004, 2008, 2010 were moderately wet.

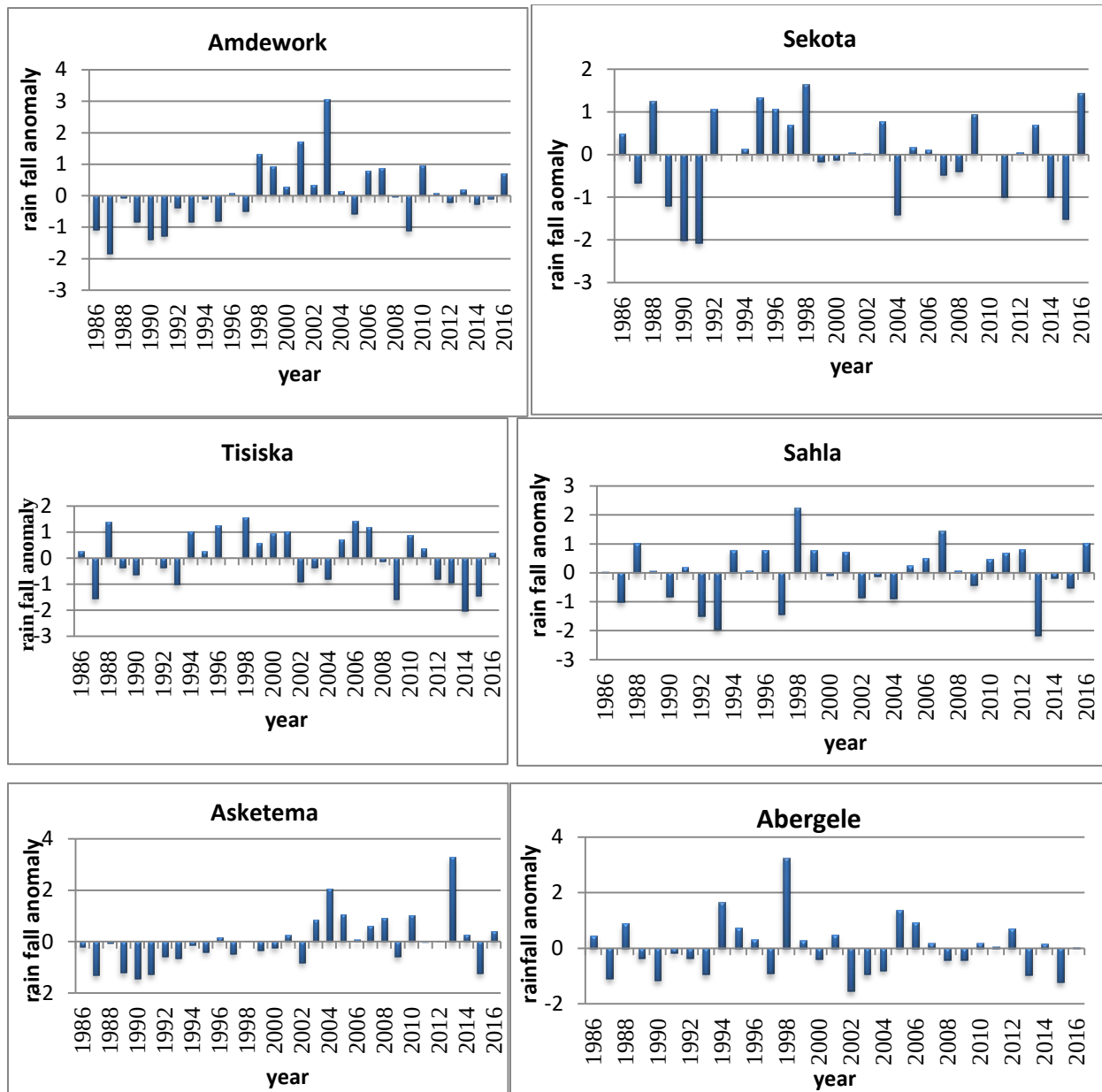


Figure 4.2. The standardized rainfall anomaly at six stations during 1986-2016

Seasonal rainfall anomaly

The result of standardized rainfall anomaly of rainfall data are given (figure 4.3)

The standardized anomalies of kiremt rainfall revealed 41-55% with weak to strong negative departure from the mean of kiremt rainfall (dry years) observed in the study area (Figure 4.3). On the other hand 45-58% were years of wet period with weak to strong positive departure from the mean kiremt rainfall in all stations.

According to von Braun (1991), for instance, a 10% decrease in seasonal rainfall from the long-term average generally translates into a 4.4% decrease in Africa food production.

The kiremt rainfall anomaly showed the driest years in 1987 and 1993 while 1990 was slight dry. Conversely years like 1998, 1999, 2001 and 2003 were the wettest years at Amdework station. At Sekota station the standardized rainfall anomaly was indicated that years like 1987, 1989, 1990, 1991 and 1993 were the driest years and 1997 and 2015 were moderate dry. At Tisiska years like 1987 and 2015 severe dry, 1993, 2009 and 2014 were moderate dry. At Sahla station years like 1997 and 2013 extreme dry, 1992 and 1993 severe dry, 1987 and 2015 were moderate dry. At Asketema station the standardized rainfall index was indicated that years like 1987 severe dry, 1989, 1990 and 1993 were moderate dry. Similarly, at Abergele station years like 1993, 1997 and 2015 were experienced severe dry while 2002 was being moderate dry occurred in the study period. In line with the present study result Viste et al., (2012) indicated that 2002 and 2009 years were found as severe to extreme Kiremt dry years over Ethiopia.

In line with this study obtained by Getaneh(2015) over North Eastern Amhara years like 1992, 1997, 2000, 2002, 2009 and 2011 were characterized by moderate to severe dry years during Kiremt season rainfall. In much of Ethiopia, similar to the Sahelian countries to its west, rainfall from June-September contributes the majority of the annual total, and is crucial to Ethiopia's water resource and agriculture operations (Diriba Korecha and Anthony, 2007). However, in the extreme case of dry, with very low total seasonal amounts, crop production suffers the most. Moreover inter-annual and seasonal variability of rainfall is a major cause of fluctuations in production of cereals in the study area. Figure (4.4) also shows that standardized inter-annual variability of the areal kiremt rainfall. It is shown that between 1986 and 1997 the kiremt rainfall has been below the long term mean excepting the years 1988 and 1994 when rainfall was slightly above the mean. On the other hand between 1998 and 2016 the kiremt areal rainfall has been above the long term mean excepting the years 2002, 2009, 2014 and 2015 when the rainfall was below the long term mean. The result of the standardized rainfall anomaly in the kiremt rainfall showed 45% dry tendency dominates and 55% dominates wet tendency over the last periods. According to drought assessment method by Agnew and Chappel (1999), there have been six driest years in the Waghemra Zone, with varying severity. There were two extreme

(1987 and 1993), three severe (1989, 1997 and 2015) and one moderate (1990) dry years. In contrast, 1998 was the wettest year in the zone over the period of record followed by the years 2001 and 2003. In general Strong negative rainfall anomalies often lead to low yield, and high yield is often associated with small rainfall anomalies. Extremely positive rainfall anomalies can also cause damages on the yield.

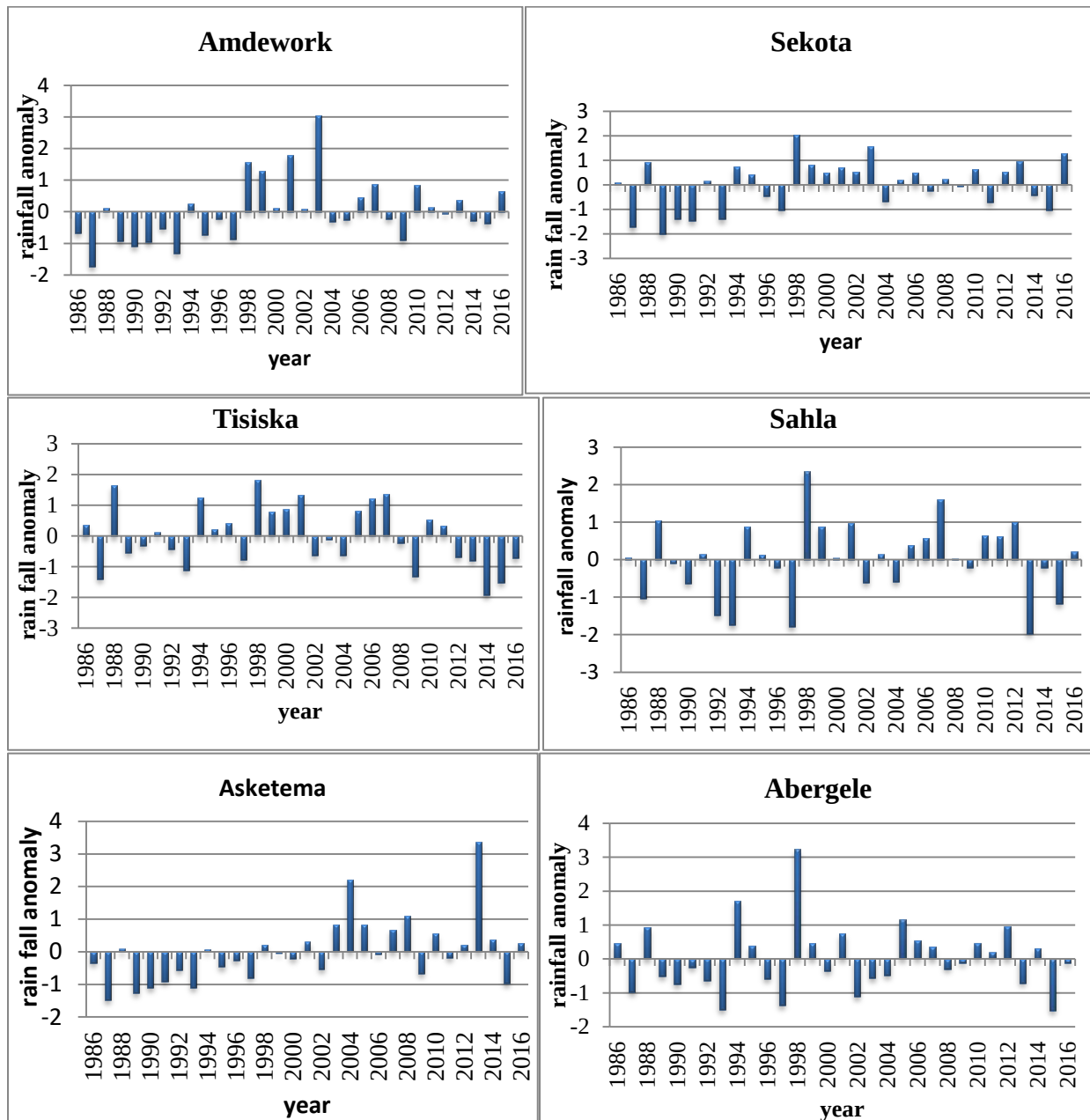


Figure 4.3. The kiremt rainfall anomaly at the selected representative stations

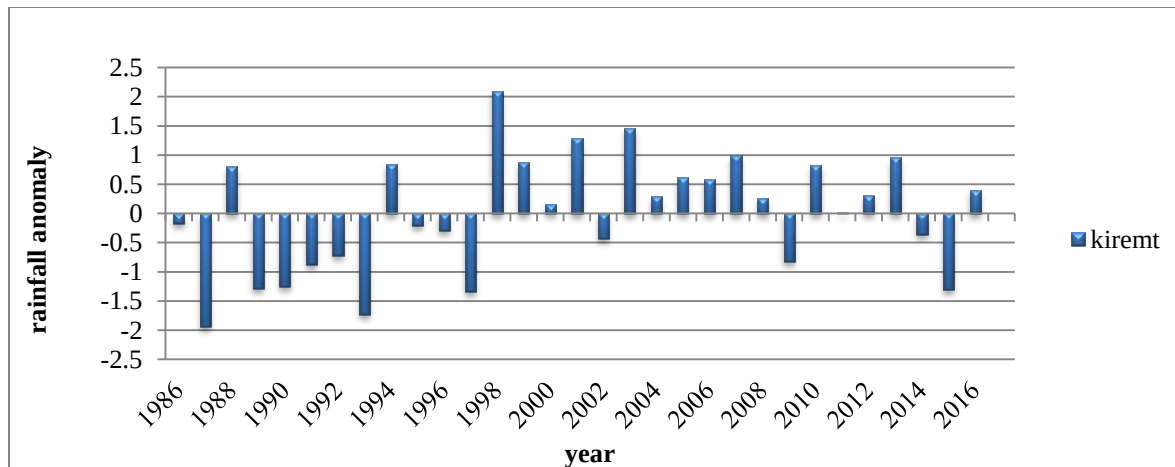


Figure 4.4: deviation of kiremt areal rainfall from the long term averages

4.1.1.2. The onset and cessation date of the kiremt season

The start date (SOS), End date (EOS) and length of the growing period (LGP) of kiremt rain fall (June-September) in the study area during 1986-2016 is depicted in (Figure4.5, 4.6, 4.7 and in (Appendix Table 1). The determination of start, end and length of the growing season, and the pattern of dry spells during the season is useful information for the planning of land preparation and planting activities. Onset date and Cessation date of the rain fall is so vital, particularly agricultural activities are highly dependent on rainfall i.e. the planting/ sowing and harvesting dates are depends on the onset and cessation of the rain fall. A delay in the onset of rains causes a short growing season and an early onset leads to a longer growing season (Sivakumar, 1988; Mupangwa et al., 2011). Yield may be significantly affected by late onset or early cessation of the season as well as damaging dry spells during the season (Ati et al., 2002; Mugalavai et al., 2008).

The onset date was varied from 153(June) at Sekota to 236 day of the year(August-23) at Tisiska stations .This indicates that the start of the growing season is early and late by a day at Sekota and Tisiska areas respectively compared to the other areas in the Waghemra Zone (AppendixTable1). The mean starting season was also ranging from 186(July-4) to 193 day of the year (July-11) which was nearly in the first and second decade of July at Amdework and Tisika stations respectively. A study by Hadigu et al., (2013), noticed comparable findings of the start date of Kiremt growing season being between 1st week of July and 3rd week of July in northern Ethiopia.

The probability of occurrence of SOS once in four years (25%percentile) corresponds to 179,180,186,181,187 and181 DOY at Amdework, Asketema,Sahla,Sekota,Tisiska and Abergele areas, respectively. Therefore earlier planting than the normal onset date is possible in all areas once out of four years' time. Whereas the probability of occurrence of SOS twice in four years (50% percentile) corresponds to 186,187,190,190,193 and 190 and three times in four years also corresponds to 195,196,196,199,199 and 194 DOY for Amdework, Asketema, Sahla, Sekota, Tisiska and Abergele areas respectively. This shows that earlier planting than195th (July13), 196th (July-14), 196th (July-14), 199th (July-17), 199th (July-17) and 194th (July-12) DOY is possible in three years every four years' time respectively. In addition the reliable planting date of cereal crops at the above areas ranges between 186-193 DOY (July4-July11).

On the other hand the mean end date of the kiremt rain season was varied from 246 day of the year (September-2) at Abergele to 261 day of the year (September-17) at Amdework station which occurred around the first and second decade of September in the last 31 years.

Therefore at all the probability levels considered, the end of the season is extended more at Amdework compared to other areas(Figure4.6) .In line with this study by Getaneh(2015) also reported that the median end date of kiremt season at kombolcha station was DOY 282(Oct-8) for the period 1992-2012. According to the classification of Hare (1983), the observed variability of Kiremt onset was less (CV = 4.6 to 9.6%) (Appendix Table1) and this shows that the onset date of Kiremt growing season have been experienced dependable patterns across the study area. Dependable pattern of sowing date is important for decision making regarding tillage, sowing and other agricultural activities. Generally, the study area characterized with the onset date varies from June 21(173 DOY) to July 28(210 DOY) with the mean onset date of the kiremt rainfall was July 8(190 DOY). The cessation of Kiremt rainfall starting from the September 1(245 DOY) to September17 (261 DOY) with mean of cessation date of September8 (252DOY).

The observed low Coefficient of variation values (2.4-4.2%) of cessation of Kiremt rainfall in the present study indicates that the ending dates for Kiremt rainfall vary over a short time span and the patterns could be more understood, and decisions pertaining harvesting and storage could be made easily. In general the dates of onset and cessation were more reliable and predictable. Because onset and cessation of rain fall determine the sowing date, crop development period and harvesting time.

4.1.1.3. Length of the growing period

The lowest length of the growing period was 13 days which was registered at Tisiska station while the highest length of the growing season was 110 days which was registered at Amdework station which shows that when the kiremt season late onset and early cessation the length of growing period becomes less and maximum length of growing period indicates that early starting date and late end date of the season (Appendix Table1& Figure 4.7).

The average length of the growing period was ranging from 58 days at Abergele to 74 days at Amdework stations during the observed period. In line with this a study obtained by Hadgu et al (2013) reported that the average length of growing period varies from 66days at Edagahamus to 85 days at Mekele stations in the Tigray region, Northern, Ethiopia for the period 1980-2009. The coefficient of variation ranged from 20.8% at Abergele to 29.5% at Tisiska areas over the last period. Higher coefficients of variation (>13%) in LGP, gives less confidence in crop selection based on maturity period.

The length of growing period revealed higher coefficient of variation than onset and cessation date in the study area (Appendix Table 1). There is a strong relationship between start date and length of the growing period ($r=0.7$) while weak correlation exists between cessation and duration of the season ($r=0.4$). The delayed onset and early cessation of the growing period resulting in shorter growing period which influences the agricultural activities. The mean start of the kiremt season in Ethiopia experiencing droughts in the recent half century caused by late onset and early cessation of seasonal rains and associated failure of the crop growing season (Alebachew ,2011). In general, the length of growing period (LGP) of the area varies from 45 days to 77.7 days with a mean of 63.8 days. The coefficient of variation (13%) which is less inter-annual variability in the length of growing period and help to plan the type of crops grown based on their maturity period.

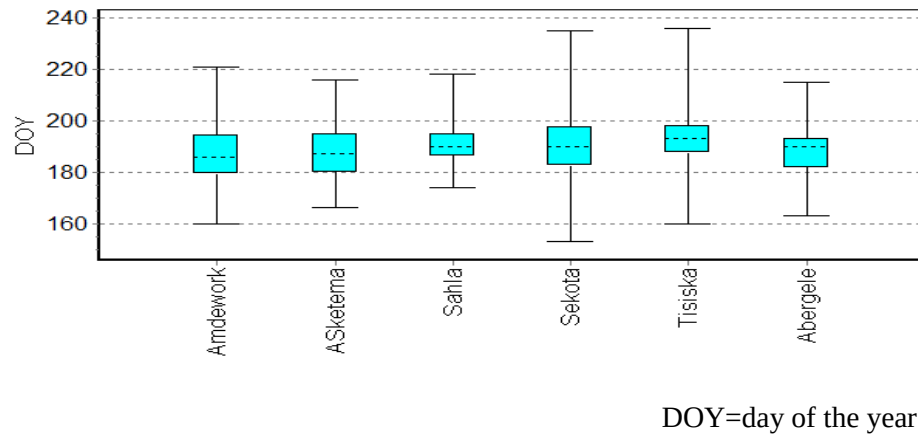


Figure 4.5. Starting of the kiremt(June-September) rainy season at six stations

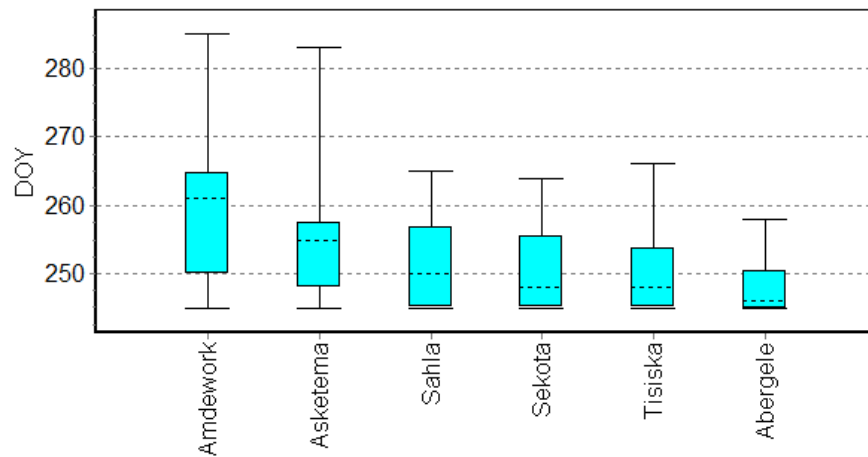


Figure 4.6. End of the kiremt rain season in the study area

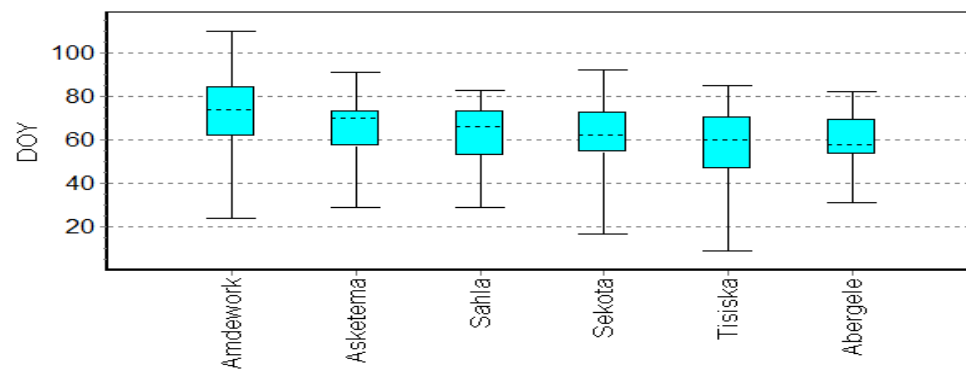


Figure 4.7.Length of the growing period in the study area

4.1.1.4. Probability of dry spell lengths

The results of the study revealed that dry spell lengths of the considered days: 5,7,10 and 15 days length varies from place to place over the study areas given in (Figure 4.8).

The information on the length of dry spells could be used for deciding a particular crop or variety, supplementary irrigation water demand and for others agricultural activities.

As indicated in the figure 4.8 the probability of dry spell occurrence during belg and kiremt seasons are different among stations. The maximum unconditional risk dry spells with length of more than 5, 7,10 and 15 days at the beginning of March (61 Days of the year) were more than 98% at Sahla,Tisiska and Abergele stations .On the other hand the probability of occurrence of dry spell length 5 and 7 days length were 99% at Amdework and Asketema stations at the beginning of March.Similarly,the dry spell occurrence at 10 and 15 days length at Amdework was 98% and 89% respectively whereas at the Asketema station was 97% and 88% with the same dry spell length at the beginning of March (61 days of the year).

The probability of 15 days dry spells occurrence gradually decrease after the 2nd decade of March to the end of April(121 days of the year) then upwards on May(122 days of the year) at Amdework,Asketema and Sekota stations .Similarly the occurrence of 10 days dry spell length was slightly decreased as the indicated month in these stations. However the probability of 5 and 7 days dry spells occurrence were maximum up to the end of May at Amdework, Asketema and Sekota stations. On the other hand the probability of 5,7,10 and 15 days dry spell length were ranging from 90% to 99% at Sahla, Tisiska and Abergele stations from March up to the end of May (152 days of the year) during belg season. The probability of 7, 10 and 15 days dry spells occurrence starting from end of June (182 days of the year) until the peak rainy period during July (183 day of the year) and 2nd decade August (224 days of the year) becomes nil (zero) at all stations while the probability of 5 day dry spells occurrence were less than 15% at all stations except at Sekota the occurrence of dry spell length was being 30 percent with the corresponding day during the study period. The probabilities of 5,7 days dry spell occurrence rapidly increases after the first decade of September(245 days of the year) while 10 and 15 days dry spells were gradually increase from the first decade of September to end of September. Generally, the shorter dry spell events have higher probability of occurrence, compared to the longer ones in general. The Belg (FMAM) season has higher probability of dry spells than the

Kiremt (JJAS) and is liable to meteorological drought. The challenges of risk of dry spell were more at Sahla ,Tisiska and Abergele as compared to other three stations. Hence crop production during this particular period needs a due attention and monitoring of planted crops. This implies that the risk of planting long cycle before June is above 65% .The probability of dry spell is higher during the early parts of the growing season, which continues to decrease up to the peak of the rainy season and increases further towards the end of the season. Crop water stress due to a soil water deficit is often associated with dry spells, particularly with dry spells longer than, 10 and 15 days. Moreover, the probabilities of all dry spell length are very low in Kiremt season. Therefore, crop is less likely affected by moisture stress.

The longer dry spells pose greater adverse impacts for crops whereas the intensity of the impact depending on the sensitivity of crop types and varieties to water deficit, at any of their critical growth stages', whereas, the shorter dry spells may not exert significant adverse impact for most.

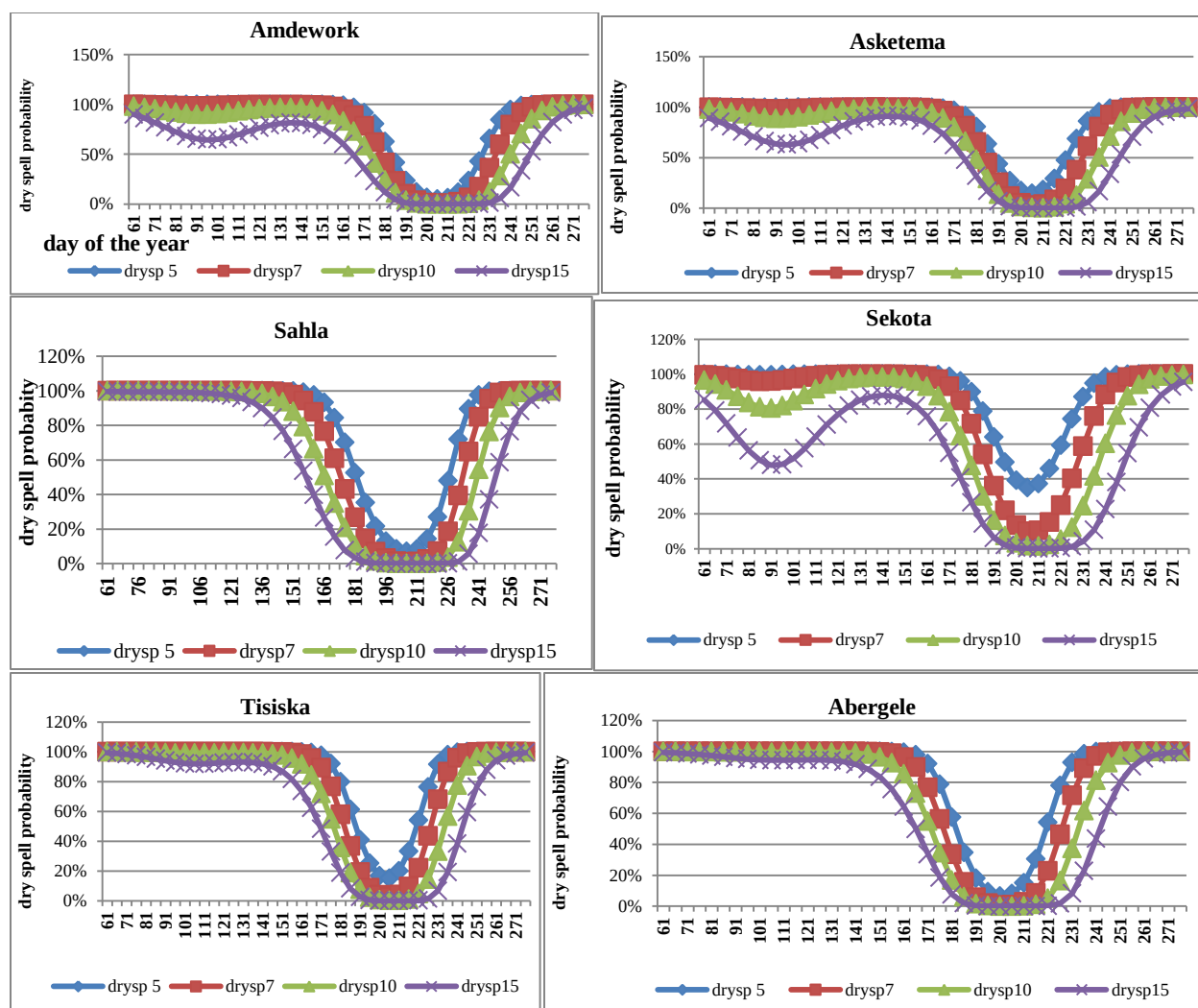


Figure 4.8. Probability of dry spell length

4.1.1.5. The number of rainy and dry day's variability

The minimum number of rainy days during the kiremt season was 20 days which was recorded at Sekota station while the maximum number of rainy days was 84 which was registered at Amdework and Asketema stations (Appendix Table 2). The average number of rainy days per year ranges from about 42 at Sekota to 62 at Amdework station. In line with this study by Kelemu .S ,(2016) also reported that the average number of rainy days were ranging from 76 at Nefas Mewcha to 88 at Debre Tabor in the South Gonder Zone, Ethiopia. The number of rainy days coefficient of variation was higher at Asketema ($V=24.2\%$) whereas the lowest coefficient of variation was observed ($CV=15.8\%$) at Sahla station during the study period. From agricultural point of view, high inter annual variability in the number of rainy days shows

less dependability of the rains for planning activities which may lead to crop failures. Particularly, the high variability of rainy days for the kiremt season could be a great problem for farmers who lack instruments to quantify rainfall amount but rather depend on number of rainy days to plan cropping calendar. On the other hand, the number of dry days was ranging from 38 days at Amdework and Asketema stations to 102 days at Sekota station (Appendix Table 2& Figure 4.9).The mean number of dry days varied from 60 days at Amdework to 80 days at Sekota station during kiremt growing season. In line with this Degefu, W. and Bewket,W.(2014) revealed that the number of dry days in a year vary from 236 days at Jinka to 279 days at Keyafer with trends being significantly increasing by 2.9 days/year at Sawla, and conversely significantly decreasing at Welayta-Sodo. The number of dry days coefficient of variation showed higher at Asketema($cv=18.9\%$) while lower coefficient of variation ($cv=10.7\%$) at Sekota station. Generally the area is characterized with areal number of wet days ranging from 31to 63 days with a mean number of wet days 53 days and with standard deviation and coefficient of variation 7.5 days and 14.2% respectively. There is also inverse relationship between the start and the number of wet days in a growing season($r=-0.13$).A delayed start of the growing season is likely to be accompanied by a reduction in the number of wet days in a growing season implying a high risk of soil water deficits in the smallholder cropping systems during the growing season.

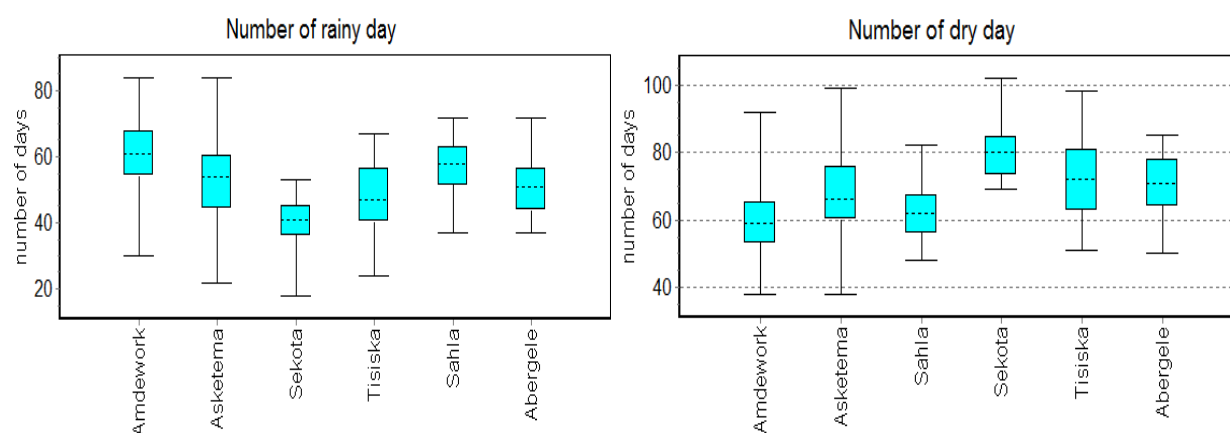


Figure 4.9. Number of rainy and dry days

4.1.1.6. The observed number of heavy rainfall and rainfall intensity

The average number of days with heavy rainfall per year varies from 3.6 at Abergele to 13.5 at Amdework station similarly intensity of rainfall on average per rainy day ranged from 9.1mm

per day at Abergele to Asketema during the last 3 decades (Table 4.4). The coefficient of variation value revealed that extremely inter-annual variations of number of heavy rainfall were observed at all stations for the last 30 years. On the other hand the coefficient of variation showed that moderate fluctuation ($30\% > cv > 20\%$) of intensity of rainfall at Amdework, Sekota and Abergele stations while at Asketema station the inter-annual variation of rainfall intensity was high ($cv = 30\%$). Conversely the average rainfall intensity at Sahla and Tisiska stations low coefficient of variation ($CV < 20\%$) were observed which indicates that the year to year fluctuation of rainfall intensity was minimum (Table 4.4). Excessive rains are generally associated with crops loss due to floods that wash away the crops or make them rot in the gardens. Moreover, too much rain affects post-harvest handling of the crops and can result into substantial post-harvest losses. Besides, in the early stages of crop production, excessive rains can lead to erosion of top soils and leaching of soil nutrients, thereby affecting productivity. Other effects of excess rainfall on crop production include poor pollination, seed and fruits formation. In general Heavy rainfall events leading to flooding can wipe out entire crops over wide areas, and excess water can also lead to other impacts including soil water logging, and reduced plant growth.

Table 4.4. Summary statistics of number of heavy rainfall and rainfall intensity in the study area

Stations	Number of heavy rainfall			Rainfall intensity		
	Mean	SD	CV (%)	Mean	SD	CV (%)
Amdework	13.5	13.1	96.1	13.9	2.9	20.4
Asketema	11.2	12.3	109.8	14.3	4.4	30.5
Sahla	4.4	3.2	73.5	9.8	1.4	14.1
Sekota	7.3	4.8	65.1	14.2	3.4	23.9
Tisiska	4.9	3.2	65.5	10.3	1.8	17.2
Abergele	3.6	2.6	72	9.1	1.8	20.1
Areal mean	7.48	6.53	80.3	19.3	2.6	21.1

SD indicates standard deviation, CV=coefficient of variation in percent

4.1.2. Observed rainfall trends

Observed annual and seasonal rainfall trend analysis result

The annual rain fall showed an increasing trend at Amdework, Asketema and Sahla stations by a factor of 13, 15.2 and 1.3 mm rainfall per year respectively (Table 4.5). The result of annual rain fall probability value showed significant trend in both Amdework and Asketema stations but in Sahla station non-significant trend has been observed during the past 31 years. In line with this Abiy Gebremichael et al., (2014) reported that annual rainfall showed an increasing trend by 3.93 mm/year in Indibir station over the study period of 1982-2012. On the contrary the annual rain fall showed a non-significant decreasing trend at Sekota, Tisiska and Abergele stations by a factor of 1.6, 3.5 and 0.5 mm per year respectively. Similarly Seleshi, (2004); Cheung and McSweeney C., (2008); Viste, et al., (2012); NMA, (2007) also reported statistically non-significant declining tendency in annual rainfall across Ethiopia between of 1960-2006. On the other hand the kiremt seasonal rain fall showed increasing trend at Amdework, Asketema Sahla and Sekota stations by a factor of 11.2, 16.2, 0.9 and 4.6 mm per year.

The result of kiremt rain fall probability value showed significant trend at Amdework and Asketema. However, at Sahla and Sekota stations did not show statistically significance trend in the time series (Table 4.5). In line with this study Getaneh (2015) also reported that kiremt seasonal rain fall shows an increasing trend by a factor of 6.38 mm per year in Kombolcha station during the period 1992-2012. Moreover, kiremt rain fall was non-significant decreasing trend by a factor of 3.8 mm per year at Tisiska station during the past 3 decades (Table 4.5).

The Belg rain fall showed non-significant increasing trend at Amdework and Tisiska stations by a factor of 1.77 and 0.47 mm per year respectively, conversely non-significant decreasing trend was observed at Asketema and Sekota by a factor of 0.64 and 3.17 mm per year (Table 4.5). Similarly, Dereje et al., (2012) also found decreasing trend of belg rain fall was identified at Kombolcha and Sirinka stations. Moreover, the Belg rainfalls at Sahla station neither increasing nor decreasing trend was observed (Table 4.5). Generally, the result showed the areal annual and kiremt rainfall have been non-significant increasing trends while the belg rainfall has been decreasing trends in the Waghemra Zone over the last periods.

Table 4.5.Trends of annual and seasonal (Belg and Kiremt) rainfall totals at six statins during 1986-2016.

stations	Annual(January-December)			Kiremt(June-September)			Belg(February-May)		
	ZMK	Q	p-value	ZMK	Q	p-value	ZMK	Q	p-value
Amdework	0.32	13.0	0.01*	0.28	11.2	0.03*	0.21	1.8	0.11**
Asketema	0.42	15.2	0.001*	0.41	16.2	0.001*	-0.08	-0.6	0.52**
Sahla	0.08	1.3	0.55**	0.06	0.9	0.67**	-0.02	0	0.91**
Sekota	-0.05	-1.6	0.74**	0.19	4.6	0.14**	-0.18	-3.2	0.15**
Tisiska	-0.12	-3.6	0.35**	-0.16	-3.8	0.20**	0.09	0.5	0.49**
Abergele	-0.06	-0.5	0.66 **	0.06	1.4	0.67**	-0.12	-0.6	0.34 **
Areal mean	0.19	3.7	0.15**	0.20	5.4	0.11**	-0.04	-0.3	0.76**

Zmk is mann-kendall's trend test, Q is sen's slope (change per year or decade),* indicates statistically significant trend when p-value< 5%(0.05), **is non-significant when p-value $\geq$ 5% or at 0.05 probability level,

The onset and cessation date and length of growing period trend result

The Mann-kendall's trend test on starting of kiremt rain fall showed anon-significant decreasing trend at Amdework and Asketema stations by a factor of 4.7 and 3.2 days per decade respectively (Table 4.6). The decreasing trend in onset date shows early starting of kiremt rain fall in the past 3 decades. On the other hand, the increasing trend of the onset date was observing at Sahla,Sekota ,Tisiska and Abergele stations by afactor of 2,6.4,5.4 and 3.2 days per decade respectively.

The observed trend showed non-significant trends at Sahla ,Abergele and Sekota stations while in Tisiska station showed significant trend. In line with this Getaneh(2015) reported that non-significant decreasing trend was observed at Lalibela station conversely non –significant increasing trend in start date of the kiremt growing season at Kombolcha,Kobo and Sirinka stations in the North Eastern, Ethiopia for the period 1992-2012.The increasing trend of onset date indicates that late onset of the kiremt rainfall in the past 3 decades which affects the agricultural activities such as land preparation and sowing dates of the crops.

The trend analysis on cessation date in kiremt season showed increasing trend at Amdework, Asketema, Sahla, Sekota and Abergele stations by a factor of 5.6, 2.5, 1.4, 0.1 and 1.1 days per decade respectively (Table 4.6). The increasing trend revealed statistically significant at Amdework and Asketema stations whereas at Sahla, Sekota and Abergele stations the probability value indicates non-significant trend. A study by Hadigu et al., (2013) reported that significantly increasing trends of cessation of kiremt season rainfall at Mekele and Adigudum stations in the Northern Ethiopia. The increasing trend of the ending date shows late cessation of the kiremt rain fall conversely decreasing trend shows early cessation of the rain.

The ending date of kiremt rain season at Tisiska station showed a non-significant decreasing trend by a factor of 1.3 days per decade which indicates that early cessation of the main rain season in the last 31 years. The length of the growing period showed a decreasing trend at Sekota, Tisiska and Abergele stations by a factor of 8.2, 7.8 and 1.4 days per decade respectively and the observed trend was non-significant at Abergele whereas significant trend at Tisiska and Sekota stations. In line with this by Kelemu, S. (2016) reported that decreasing trends of the length of the growing period at Debretabor and Wereta stations in South Gondar zone, Amhara regional State, Ethiopia for the period 1985-2014.

On the other hand the length of the growing season showed increasing trend in the remaining stations. Generally, the Mann-kendall's trend test showed both onset and cessation date have been non-significant increasing trends which indicates that early onset and cessation of the kiremt season were observed in the study area. Likewise the length of growing period also increasing trends observed. However the detected trend was non-significant.

Table 4.6 .Trends of onset date, cessation date and length of growing period during kiremt season at six stations for the period 1986-2016

stations	Onset date			Cessation date			Length of growing period		
	ZMK	Q	p-value	ZMK	Q	p-value	ZMK	Q	p-value
Amdework	-0.21	-0.5	0.11**	0.35	0.6	0.01*	0.33	0.9	0.01*
Asketema	-0.18	-0.3	0.16**	0.23	0.3	0.01*	0.25	0.7	0.06**
Sahla	0.13	0.2	0.29**	0.24	0.1	0.076**	0.27	0.6	0.03*
Sekota	0.23	0.6	0.07**	0.02	0.01	0.90**	-0.25	-0.8	0.05*
Tisiska	0.25	0.5	0.04*	-0.16	-0.1	0.23**	-0.29	-0.8	0.03*
Abergele	0.18	0.3	0.16**	0.18	0.1	0.196**	-0.089	-0.1	0.496**
Areal mean	0.16	0.15	0.21**	0.21	0.16	0.095**	0.12	0.14	0.332**

The observed trends of the number of rainy and dry days in the kiremt season (JJAS)

The Mann-kendall's trend test in the number of rainy days indicated that a non –significant increasing trend at Amdework,Asketema,Sahla and Sekota stations by a factor of 1.9,1.2,3.6 and 1.4 days per decade respectively while at Tisiska and Abergele stations non-significant decreasing trend were observed by a rate of 4.7 and 1.6 days per decade respectively during the main rainy season (Table 4.7). On the other hand the number of dry days showed a non-significant decreasing trend at Amdework,Asketema, Sahla and Sekota stations by 1.8,1.3,3.6 and 0.9 days per decade while at Tisiska and Abergele stations the number of dry days were increasing trend by a factor of 5.8 and 2.5 days per decade respectively in the observed years .However the result of the number of dry days did not reveal significant trend at Abergele station where as at Tisiska significant trend was registered in the study area. In line with this by Degefu, W. (2014) reported that number of rainy day was significantly decreasing by 2.8 days a year atSawla. Conversely significantly increasing by 6 days/ year at Welayta-Sodo in the Omo-Ghibe River Basin, Ethiopia.

In general the decreasing trend and the variations in rainfall affected farmers' ability to determine the onset of the rainy season and also the most suitable planting period.

Table 4.7. Trends of the kiremt season number of rain and dry days, at six stations for the period 1986-2016.

stations	Number of rain days			Number of dry days		
	ZMK	Q	p-value	ZMK	Q	p-value
Amdework	0.14	0.19	0.28**	-0.13	-0.18	0.29**
Asketema	0.06	0.12	0.62**	-0.07	-0.13	0.61**
Sahla	0.24	0.36	0.06**	-0.24	-0.36	0.06**
Sekota	0.09	0.14	0.48**	-0.05	-0.09	0.68**
Tisiska	-0.24	-0.47	0.06**	0.28	0.58	0.03*
Abergele	-0.16	-0.25	0.21**	0.16	0.25	0.23**
Areal mean	0.021	0.042	0.878**	-0.024	-0.042	0.865**

The number of heavy rainfall and simple daily intensity index

Based on the Mann-kendall's trend test the annual number of heavy rainfall showed statistically significant increasing trend at Amdework and Asketema stations by a factor of 2.8 and 5 days per decade respectively while at Sahla, Tisiska and Abergele stations a decreasing trend were observing by a rate of 1.5, 0.2 and 0.4 days per decade (Table 4.8). However the annual number of heavy rainfall did not reveal statistically significant trend at Tisiska and Abergele stations conversely significant trend at Sahla station. On the other hand during the main rainy season (kiremt) the number of heavy rainfall showed statistically significant increasing trend at Asketema and Sekota stations by a factor of 5 and 1.9 days per decade similarly at Amdework station statistically non-significant trend was observing by 2.5 days per decade conversely at Sahla, Tisiska and Abergele stations the number of heavy rainfall were showing decreasing trend during kiremt season.

The result of the Mann-kendall's value revealed that non-significant at Tisiska and Abergele stations where as at Sahla the probability value showed statistically significant trend. In line with this by Kelemu (2016) reported that decreasing trends on the number of heavy rainfall at Debretabor station by a factor of 0.8 days per decade in South Gonder zone, Amhara regional State, Ethiopia for the period 1985-2014. Moreover, the annual simple daily intensity index

showed increasing trend at Amdework, Asketema, Tisiska and Abergele stations by a factor of 1.4, 1.8, 0.2 and 0.7 mm per day respectively (Table 4.8). However, the probability value did not reveal statistically significant trend only at Tisiska station. At Sahla and Sekota stations the daily intensity rainfall were showing a non-significant decreasing trend by 0.4 and 0.1 mm per day respectively. Additionally during kiremt rain season the daily intensity rainfall were showing increasing trend by a factor of 1.2, 2.1, 0.5 and 0.6 mm per day at Amdework, Asketema, Sekota and Abergele stations respectively. However, the probability value of simple daily intensity rainfall revealed statistically significant trend at Amdework and Asketema stations whereas at Sekota and Abergele did not reveal significant trend during the main rain season (kiremt). On the other hand the daily intensity rainfall showed a non-significant decreasing trend by a factor of 0.4 mm per day at Sahla and Tisiska stations during kiremt rain season.

Table 4.8. Trends of number of heavy rainfall and simple daily intensity index during annual and kiremt rainfall season in the study area.

Stations	Extreme event	Annual			Kiremt		
		ZMK	Q	p-value	ZMK	Q	p-value
Amdework	Heavy rain	0.26	0.28	0.041*	0.23	0.25	0.076**
	SDII	0.29	0.14	0.024*	0.28	0.12	0.029*
Asketema	Heavy rain	0.41	0.5	0.002*	0.43	0.5	0.008*
	SDII	0.28	0.18	0.029*	0.39	0.21	0.002*
Sahla	Heavy rain	-0.34	-0.15	0.01*	-0.33	-0.15	0.014*
	SDII	-0.19	-0.04	0.121**	-0.23	-0.04	0.066**
Sekota	Heavy rain	0.24	0.17	0.063**	0.34	0.19	0.012*
	SDII	-0.23	-0.11	0.072**	0.16	0.05	0.221**
Tisiska	Heavy rain	-0.04	-0.02	0.78**	-0.095	-0.042	0.483**
	SDII	0.01	0.02	0.972**	-0.1	-0.04	0.442**
Abergele	Heavy rain	-0.17	-0.04	0.20**	-0.16	-0.04	0.232**
	SDII	0.26	0.07	0.044*	0.23	0.06	0.067**

Zmk is mann-kendall's trend test, Q is sen's slope, * is statistically significant, ** is non-significant at 0.05 probability level, number of heavy rainfall/annual count of days when rainfall ≥ 20 mm, SDII indicates simple daily intensity index/total annual rainfall per number of rainy days

4.1.3. The observed annual and seasonal temperature variability

The annual maximum temperature varied between 21.2 °C at Amdework to 34.2 °C at Tisiska while the annual minimum temperature ranges from 8.5 °C at Amdework to 20 °C at Abergele stations over the study area (Appendix Table 3). Similarly, the highest annual temperature was 26.5 °C which occurred at Tisiska followed by 26.4 °C at Abergele stations whereas the lowest being was 15.2 °C at Amdework followed by 16.4 °C Asketema stations (Appendix Table 3).

The areal mean annual maximum temperature ranged from 24.6-30.5 °C with a mean of 26.3 °C while the areal annual minimum temperature varies from 10.7-15.6 °C with a mean of 15.9 °C. Likewise the areal mean annual temperature was between 17.9 and 22.8 °C with a mean of 19.3 °C and standard deviation of about 1.1 and coefficient of variation 5.7%. Additionally, the kiremt maximum temperature ranged between 19.1 °C at Amdework to 33.9 °C at Abergele areas while the minimum temperature ranged from 8.1 °C to 19.9 °C at Amdework and Abergele stations respectively (Appendix Table 4). The areal kiremt maximum temperature ranged from 23.1-30.2 °C with a mean of 24.7 °C whereas the minimum temperature ranged 11.1-15.9 °C with a mean of 13.1 °C over the study area.

The inter-annual and seasonal fluctuation of maximum and minimum temperature was expressing in terms of coefficient of variability over the last 31 years at the six stations shown in (Appendix Table 3). The coefficient of variability for annual maximum temperature ranged from 2.9% at Sekota to 8.6% at Tisiska with the corresponding standard deviation of 0.78 and 2.4 respectively while for annual minimum temperature ranged from 6.1% at Sekota to 15.6% at Tisiska stations. The kiremt maximum and minimum temperature coefficient of variation for the study area ranged from 4.6% Sekota to 12% Tisiska and 7.5% Asketema to 14.3% respectively (Appendix Table 4). During kiremt season the temperature was ranging from 14.1 °C at Amdework to 26.6 °C at Abergele stations (Appendix Table 4). Temperature extremes beyond the optimal range causes stress, injuries and productivity loss to crops. According to Jones (2013) the timing of heat stress in relation to crop development and the conditions under which it is grown determines extent of productivity loss.

Generally, the study area is characterized with mean annual maximum temperature varies from 24.6°C to 30.5°C with mean of 26.3°C. The mean annual minimum temperature also varies from 10.7°C to 15.6°C with a mean of 12.3°C. In addition the mean annual temperature varies from

17.9°C to 22.8 °C with a mean of 20.3°C over the last 3 periods. The coefficient of variation is higher for minimum temperature than maximum and average temperature in all study station (Appendix Table 3).The mean monthly minimum Temperature varies between 10°C in December to 14.1°C in May and June and mean monthly maximum Temperature varies between 22.9°C on August to 28.4 °C in March and May. Furthermore the monthly mean Temperature varies between 17.8°C in August to 21.2°C in May (Figure4.10).This indicates that variation of minimum, maximum and mean temperature were found in every month.

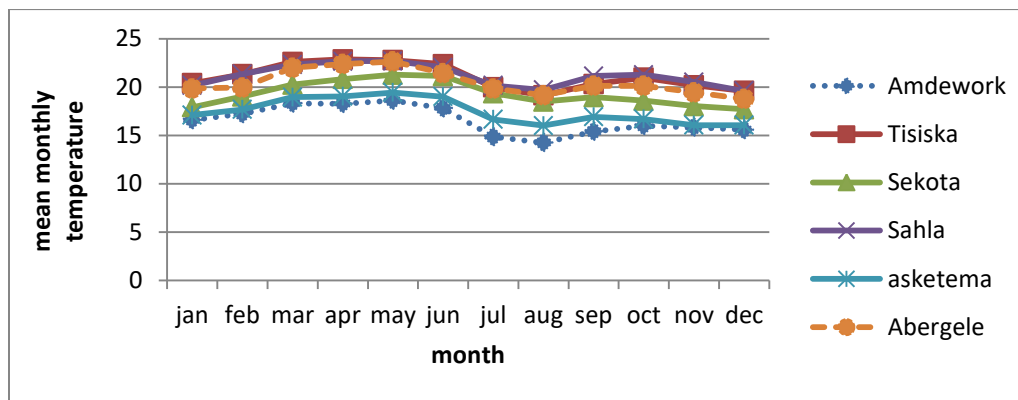


Figure 4.10.Observed mean monthly temperature at all stations

4.1.3.1. Temperature anomaly

The standardized temperature anomaly analysis shows that strong to weak negative and positive departure from the long term mean temperature in the study area during the period 1986-2016 (Figure 4.11).A temperature anomaly is the difference from an average, or baseline, temperature. The baseline temperature is typically computed by averaging 30 or more years of temperature data. A positive anomaly indicates the observed temperature was warmer than the baseline, while a negative anomaly indicates the observed temperature was cooler than the baseline. The result of standardized temperature anomaly24 years (77.4%) showed negative anomalies at Tisiska station of the 31 years of observation. The persistence of negative anomalies for these years indicated that the study area had known cold conditions from all selected stations. In contrast 16 years (51.6%) of the study period had warm period with strong to weak positive departure from the mean of the annual temperature at Amdework station which showed more number of hot years were observed from the other stations. The anomalies in the annual and seasonal areal temperature are shown in figure4.12.

The temperature in the study area is characterized by alteration of cold and hot years in periodic pattern. The standardized anomaly index shows the hottest years particularly from 2012-2016 on both annual and seasonal pattern. On the other hand years like 1990 and 1993, 1990 and 1999, and 1989 and 1993 were the coldest years on record annually, kiremt and belg seasonal temperature respectively (Figure 4.12).

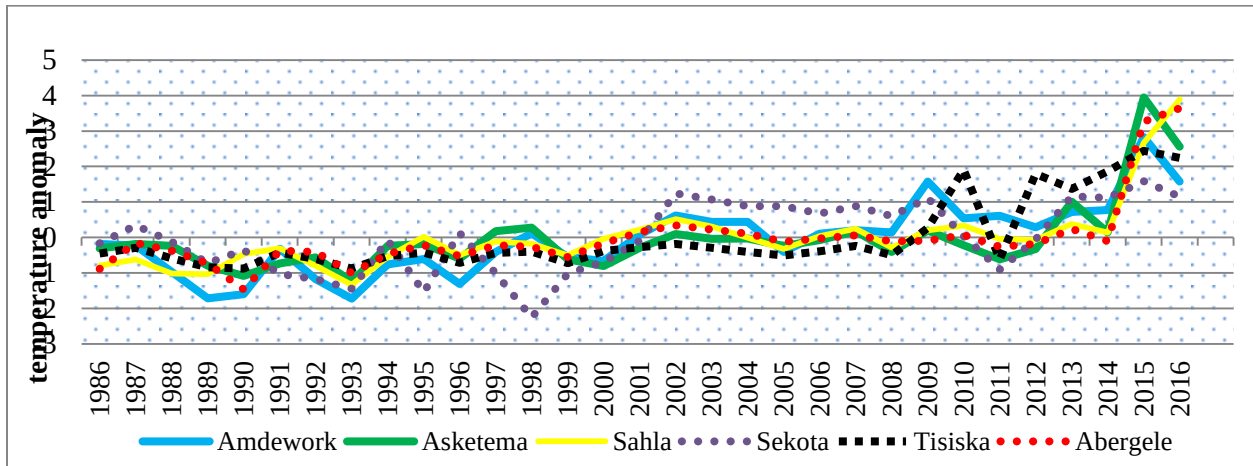


Figure 4.11: standardized temperature anomaly at the selected stations

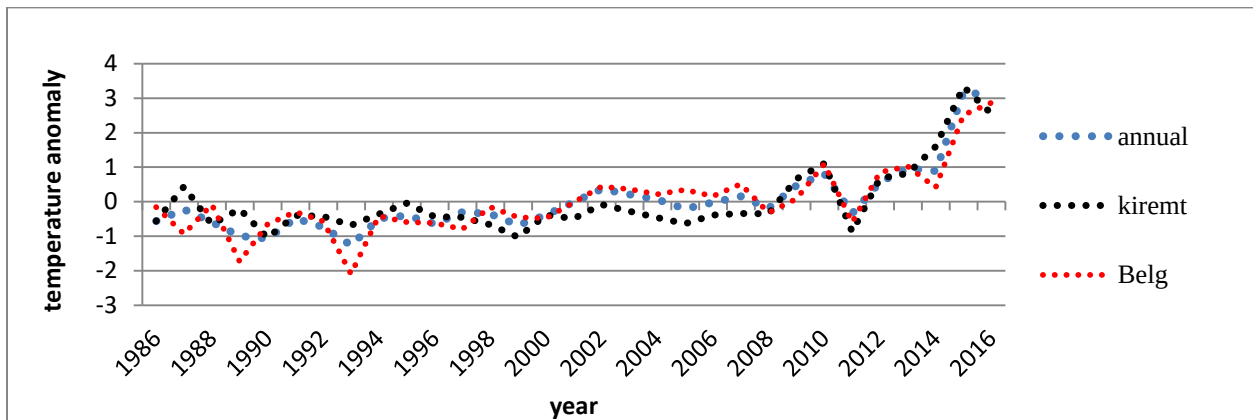


Figure 4.12: deviation of annual and seasonal areal temperature from the long term averages

4.1.3.2. The number of warm night and day, and the number of cold day and night

The number of warm night was ranging from 10.4 days at Amdework to 23.8 days at Abergele stations while the number of cool night ranging from 4 days at Sekota to 16.9 days at Sahla stations in the study period (Appendix in Table 6). On the other hand the number of warm day

was ranging from 24.2 days at Amdework to 37.8 days at Tisiska stations where as the number of cold day varies from 9days at Sekota to 30.6 days at Abergele station (Appendix Table 6). Based on Hare(1983) classification the coefficient of variability showed less variation ($CV < 10\%$) on the number of warm day and warm night at all stations which indicates that low inter- annual fluctuations in the study area. On the other hand the coefficient of variation on the number of cool day varies from 6.7 % at Amdework to 20.2% Sekota stations while the number of cool night ranged from 13.1 %at Amdework to 23.3% at Tisiska stations annually during the study period (Appendix in Table6).

4.1.4. Observed temperature trend analysis result

The annual maximum temperature showed significant increasing trend at Amdework, Asketema, Sahla, Sekota , Tisiska and Abergele by a factor of 0.58, 0.29, 0.61, 0.63, 1.09 and 0.6 °C per decade respectively for the study period in (Table 4.9). In line with this obtained by Nigusie.A, (2015) in Tigray region found that an increasing trend of the annual maximum temperature by 0.018 °C per year, but negative trend was observed in minimum temperature by -0.038 °C per year for period of record (1995-2014). Similarly, in the kiremt season the mean maximum temperature showed statistically significant increasing trend at Amdework, Sahla ,Tisiska and Abergele stations by a factor of 0.63, 0.84 , 1.24 and 0.6 °C per decade respectively.

Similarly a non-significant increasing trend was observed at Asketema station by 0.298 °C /decade during kiremt season (Table 4.9). USAID (2015) technical report on climate variability and change in Ethiopia reported that maximum temperatures during kiremt season vary between 0.4-0.6 °C/decade in Amhara, Oromia, Afar and Tigray region and belg season temperatures showing more rapid increases (> 0.6 °C/decade) in all region. A non-significant decreasing trend was observed at Sekota station by a factor of 0.47 °C per decade during kiremt season in (Table 4.9). Moreover, the mean maximum temperature revealed significant increasing trend at Amdework, Sekota and Tisiska stations by a factor of 0.69, 1.29 and 1.09°C per decade respectively and the non-significant increasing trend was also observed at Asketema , Sahla Abergele stations by 0.23 , 0.43 and 0.4°C per decade respectively during belg season (Table 4.9). In general the mean maximum temperature showed increasing trends by a factor of 0.7°C on annual and kiremt and 0.4°C per decade in the study area. However, the detected trends were non-significant on belg while on annual and kiremt season significant trends were observed.

Table 4.9. Trends of mean annual and seasonal (Belg and Kiremt) maximum temperature at six stations.

stations	Annual(January-December)			Kiremt(June-September)			Belg(February-May)		
	ZMK	Q	p-value	ZMK	Q	p-value	ZMK	Q	p-value
Amdework	0.49	0.06	<0.0001*	0.47	0.06	<0.0001*	0.39	0.07	0.002*
Asketema	0.27	0.03	0.032*	0.18	0.03	0.1651**	0.18	0.02	0.155**
Sahla	0.47	0.06	<0.0001*	0.56	0.08	<0.0001*	0.21	0.04	0.103**
Sekota	0.49	0.06	<0.0001*	-0.19	-0.05	0.1452**	0.68	0.13	<0.0001*
Tisiska	0.52	0.11	<0.0001*	0.47	0.12	<0.0001*	0.42	0.11	0.001*
Abergele	0.44	0.06	0.0004 *	0.41	0.06	0.001 *	0.23	0.04	0.07 **
Areal mean	0.63	0.07	<0.0001*	0.51	0.07	<0.0001*	0.24	0.04	0.05**

The annual mean minimum temperature showed significant increasing trend at Amdework, Asketema, Sahla, Sekota , Tisiska and Abergele by a factor of 0.70, 0.29, 0.73, 0.29 , 0.73 and 0.62°Cper decade respectively during 1986-2016 in (Table 4.10). A study reported by Solomon *et al.*, (2015) comes across with an increasing trend in annual minimum temperature at Lake Tana by a factor of 0.423 °C per year.

The minimum observed positive rate of change in mean annual minimum temperature over the study area was 0.29 °C per decade at Sekota station. At the seasonal level, the mean minimum temperature showed significant increasing trend at Amdework, Asketema, Sahla ,Tisiska and Abergele stations by a factor of 0.59, 0.31, 0.67 , 0.69 and 0.58 °C per decade respectively where as non-significant decreasing trend was observed at Sekota station by a factor of 0.55 °C during kiremt season in (Table 4.10). Moreover, mean minimum temperature showed significant positive trend atAmdework, Sahla, Sekota, Tisiska and Abergele stations by a factor of 0.78, 0.66, 0.39, 0.63, 0.54 °C per decade while non-significant increasing trend was observing at Asketema by a factor of 0.33 °C during belg season (Table 4.10). In general the mean minimum temperature showed significant increasing trends by a factor of 0.6°C , 0.4°C and 0.7°C per decade at annual, kiremt and belg seasons respectively in the study area.

Table 4.10.Trends of mean annual and seasonal (Belg and Kiremt) minimum temperature at five stations in Waghemra Zone.

stations	Annual(January-December)			Kiremt(June-September)			Belg(February-May)		
	ZMK	Q	p-value	ZMK	Q	p-value	ZMK	Q	p-value
Amdework	0.55	0.1	0.1001*	0.38	0.06	0.0021*	0.5355	0.08	<0.0001*
Asketema	0.38	0.03	0.0021*	0.29	0.03	0.02*	0.1957	0.03	0.13**
Sahla	0.51	0.07	<0.0001*	0.41	0.07	<0.0001*	0.5011	0.07	0.0001*
Sekota	0.27	0.03	0.0316*	-0.38	-0.05	0.002*	0.2731	0.04	0.03*
Tisiska	0.51	0.07	<0.0001*	0.42	0.07	0.001*	0.2774	0.06	0.02*
Abergele	0.53	0.06	<0.0001 *	0.37	0.06	0.003*	0.41	0.05	0.001*
Areal mean	0.58	0.06	<0.0001*	0.39	0.04	0.002*	0.539	0.07	<0.0001*

Annual and seasonal temperature trend

The result from the Mann-kendal analysis on annual mean temperature showed statistically significant increasing trend by a factor of 0.69, 0.3, 0.59, 0.37, 0.95 and 0.53 °C per decade at Amdework, Asketema, Sahla, Sekota, Tisiska and Abergele stations respectively in (Table 4.11). World Bank (2011) reported that the mean annual temperature increased by the rate of 0.28 °C per decade between 1960 and 2006 and Ekpoh.J.,&Nsa,E.(2011) have argued that anthropogenic climate change may increase the likelihood of such events occurring.

At the seasonal level, the kiremt mean temperature showed significant increasing trend by a factor of 0.63, 0.29, 0.68,1 and 0.5 °C at Amdework, Asketema, Sahla,Tisiska and Abergele stations respectively conversely significant decreasing trend was observing at Sekota station by 0.64 °Cper decade in (Table 4.11).Similarly, during belg season significant a positive trend were observing at Amdework,Sahla,Sekota,Tisiska and Abergele stations by a factor of 0.75,0.48,0.88,0.93 and 0.48 °C per decade on the other hand non-significant positive trend also observed at Asketema station by a factor of 0.26 °C during belg season in the study period.

Generally, the Mann-kendal trend test showed that the average annual minimum and maximum temperatures have been increasing by about 0.6 °C and 0.7 °C per decade, respectively, over the past 3 decades in Waghemra Zone.

Similarly the areal mean temperature has been increasing by a rate of about 0.7°C, 0.4°C and 0.8°C per decade on annual, kiremt and belg seasons respectively. The detected trends were significant at annual and seasonal level.

The positive value of Sen's Slope for annual and seasonal temperature is an indication of increasing trend, which might be associated with global warming and climate change.

The most likely explanation for the temperature increase might be carbon dioxide and other heat trapping "greenhouse" gases that human activities produce. According to IPCC (2007) rise in temperature will distress crops and plants require more water to replenish loss in the form of irrigation.

Table 4.11: Trends of mean annual and seasonal (Belg and Kiremt) temperature at six stations in Waghemra Zone.

stations	Annual(January-December)			Kiremt(June-September)			Belg(February-May)		
	ZMK	Q	p-value	ZMK	Q	p-value	ZMK	Q	p-value
Amdework	0.63	0.07	<0.0001*	0.56	0.06	<0.0001*	0.56	0.07	<0.0001*
Asketema	0.37	0.03	0.003*	0.29	0.03	0.024*	0.187	0.03	0.15**
Sahla	0.59	0.06	<0.0001*	0.58	0.07	<0.0001*	0.363	0.05	0.0037*
Sekota	0.42	0.04	0.001*	-0.34	-0.06	0.01*	0.544	0.09	<0.0001*
Tisiska	0.52	0.09	<0.0001*	0.43	0.1	0.001*	0.411	0.09	0.001*
Abergele	0.514	0.05	<0.0001*	0.406	0.05	0.001*	0.34	0.05	0.01*
Areal mean	0.66	0.07	<0.0001*	0.381	0.04	0.002*	0.548	0.08	<0.0001*

The annual number of warm day showed increasing trend at Amdework, Asketema, Sahla, Sekota, Tisiska and Abergele stations by a factor of 0.3, 0.4, 0.5, 0.4, 1.3 and 0.4 days/decade respectively in (Table 4.12). However, the result of annual number of warm day probability value showed significant trend at all stations except at Amdework station which did not reveal statistically significant trend. In line with study, Mekasha, et al. (2014) reported significant increasing trends in annual number of warm days by 4- 6 days/decade at Metehara, Negele Borana, Ziway and Asela weather stations. At Sekota station the number of warm night showed non-significant decreasing trend by the rate of 0.3 days/decade.

The number of warm night was statistically significant increasing trend at Amdework, Sahla and Abergele stations by a factor of 0.8, 0.6 and 0.5 days per decade where as non-significant increasing trend was observing at Tisiska by 0.2 days per decade. A study by Mekasha, et al. (2014) reported significant increasing trends in the number of warm night by 0.2-1.2 days/year at Metehara, Negele Borana, Yabelo and Asela weather stations for the period 1967-2008.

More over the result from the Mann-kendal analysis on the annual number of cool day showed increasing trend At Amdework, Sahla, Tisiska and Abergele stations by a factor of 0.4, 0.4, 0.3 and 0.2 days/decade respectively. However the probability value did not reveal significant trend at Sahla, Tisiska and Abergele stations where as at Amdework statistically significant trend was observing. On the other hand the number of cool day at Asketema and Sekota stations showed non-significant decreasing trend by a factor of 0.01 and 0.7 day/decade during the study period (Table 4.12). According to McSweeney (2008) the numbers of cold days have significantly decreased by 21 days with more rapid decline in frequency of cold nights by 41 days during 1960-2003. Additionally, the number of cool night showed statistically significant increasing trend at Amdework, Asketema, Sahla, Sekota, Tisiska and Abergele stations by a factor of 0.6, 0.7, 0.7, 0.8, 0.1 and 0.9 days per decade during the last 31 years.

Table 4.12. Trend analysis of annual number of warm day and night, number of cool day and night at six representative stations during the period 1986 - 2016

stations	Warm day			Warm night			Cool day			Cool night		
	ZMK	Q	p-value	ZMK	Q	p-value	ZMK	Q	p-value	ZMK	Q	p-value
Amdework	0.18	0.03	0.17 **	0.56	0.08	<0.001*	0.32	0.04	0.014*	0.41	0.06	0.002*
Asketema	0.27	0.04	0.04*	0.17	0.02	0.18**	-0.11	-0.014	0.44**	0.47	0.07	0.0002*
Sahla	0.37	0.05	0.04*	0.44	0.06	0.001*	0.14	0.04	0.261**	0.33	0.07	0.012*
Sekota	0.31	0.04	0.02*	-0.21	-0.03	0.113**	-0.02	-0.07	0.889**	0.27	0.08	0.04*
Tisiska	0.46	0.13	0.004*	0.10	0.02	0.43**	0.08	0.03	0.529**	0.36	0.1	0.001*
Abergele	0.31	0.04	0.017*	0.41	0.05	0.001*	0.104	0.02	0.423**	0.37	0.09	0.004*
Average	0.46	0.1	0.003*	0.41	0.04	0.001*	0.03	-0.1	0.814**	0.505	-0.1	0.001*

Zmk is mann-kendal trend test, Q is sen's slope/rate of change per year, * indicates significant trend at 0.05 level, ** indicates non-significant trend at 5% probability level

In general over the last 31 years the annual frequency of warm days and night has been increased by 1 and 0.4days/decade respectively. But the number of cold days and nights has decreased by 1 day per decade in Waghemra Zone. Temperature alterations further increased evapotranspiration, thus affecting crop production and increasing farmers' vulnerability. This observation is in agreement with the study by Rowhani et al. (2011), who argued that the adaptive capacity of vulnerable smallholder farmers is significantly weakened by increased stress due to climate-change impacts.

4.2. The projected climate variability and change

4.2.1. Future rainfall variability

The projected annual and seasonal rainfall for the period 2050s and 2080s from the mean of 20 ensemble GCMs under RCP4.5 and Rcp8.5 emission scenarios in the study area is depicted in (Appendix Table 7& 8).Over the next two century (mid and end century) the probable annual and seasonal rainfall will vary based on the result of the selected ensemble mean of Global Climate Models in the study area.

The projected kiremt total rainfall will varies from 132.7mm to 1646.6mm and 142.7mm to 1666.4mm for the period 2050s and 2080s at Sekota and Amdework stations respectively under low emission scenario (RCP4.5) (Appendix Table 7) .Similarly the probable kiremt rainfall will ranges from 137.1 to 1712.1mm and 144 to 1835.7mm for the period 2050s and 2080s at Sekota and Amdework stations respectively under high emission scenario (RCP8.5) (Appendix Table 7). Under both scenarios the lowest estimated kiremt rainfall will be observe at Sekota conversely the highest probable kiremt rainfall will be expect at Amdework station from the mean of 20 GCMs.

There is also a large –inter seasonal variability of kiremt rainfall ranging from 21% at Sahla to 47% at Asketema stations under both emission scenarios (RCP4.5&Rcp8.5) will be expect for the period 2050s and 2080s. The projected coefficient of variation in all stations revealed that kiremt rainfall will be highly variable ($CV > 30\%$) except Sahla and Abergele ($CV < 30$) which will be moderate variable at these stations (Appendix Table 7).On the other hand the projected annual total rainfall amount for the study area ranges from 254.8 to 1798.2mm for the period

2050s and 257.6 to 1807.7 mm for the period 2080s at Tisiska and Amdework stations respectively under low emission scenario (RCP4.5) (Appendix Table7) .

Similarly, the estimated rainfall in the kiremt season will varies from 269.2 to 1859 for the period 2050s and 276.1 to 1997.2mm for the period 2080s at Tisiska and Amdework stations respectively under high emission scenario RCP8.5 in (Appendix Table7).The highest coefficient of variability ($CV > 30\%$) will be expect at Asketema and Amdework stations where as the lowest will be expects at Sahla station under low and high emission scenario for the future annual total rainfall amount. The ensemble mean of the selected GCMs shows that the projected kiremt rainfall will be highly variable than the annual total rainfall at all stations except Sahla under the two representative concentration path ways for the period 2050s and 2080s.The projected contribution of kiremt rainfall to the annual rainfall will be varies from 69.6% at Sekota to 93.4% at Sahla stations for the period 2050s and 2080s under the low and high emission scenarios (Appendix Table 7). Generally the projections based on 20 combinations of GCMs with the two representative concentration path ways emission scenario suggested that the annual areal mean rainfall expected to be 621.9mm and 647.3mm under Rcp4.5 and Rcp 8.5 respectively for the period 2050s while for the period 2080s will be 629.8 mm and 668.3mm under Rcp4.5 and Rcp8.5 respectively in the study area.

Similarly results from the GCM ensemble out puts under the two Rcps the expected kiremt areal rainfall for the period 2050s will be 528.4mm and 551.4 under Rcp4.5 and 8.5 scenarios respectively where as for the period 2080s the expected kiremt rainfall will be 537.8mm and 562.5 mm under Rcp4.5 and Rcp8.5 emission scenarios respectively.

4.2.1.1. The onset, cessation and length of the growing period in the mid and end-century

The onset, cessation and length of the growing season of the future mid and end-century as projected by mean of 20 Global Climate Models under low and high emission scenario in the study area is portrayed in (Appendix Table 9). The probable onset date of future kiremt rain season will vary from the earliest 154day of the year (June 2) at Amdework to the late onset 237 day of the year (August 24) at Abergele station respectively for the period 2050s under Rcp4.5 and Rcp8.5 emission scenario in the study area (Appendix Table9). On the other hand starting date of kiremt rainfall is projected to be between 154 day of the year at Amdework to 257 day of

the year at Abergele station under Rcp4.5 and 158 day of the year at Tisiska and Abergele to 251 day of the year at Sekota station under Rcp8.5 for the period 2080s.

The average onset date of the future kiremt rainfall in all stations will be expect in the first decade of July as predicted by selected Global Climate Models under low and high emission scenario over the next two century. The coefficient of variability for the future start of kiremt rainfall however revealed less variability by ensemble mean of GCMs under Rcp4.5 and Rcp8.5 emission scenario according to (Hare, 1983) classification for the period 2050s and 2080s.

The end date of the future kiremt rainfall will vary from the earliest 245 day of the year (september1) in all stations to the late cessation 290 day of the year (October 16) at Abergele station for the next two century under Rcp4.5 and Rcp8.5 emission scenarios.

The mean cessation date of the future kiremt rain fall in most stations will be in the first decade of September except Amdework and Abergele stations. The average end date will expect in the second decade of September at Amdework while at Abergele station the projected cessation date will be expect nearly in the third decade of September as predicted by Global Climate Models for the period 2050s and 2080s under low and high emission scenarios.

The coefficient of variability for the future end date of kiremt rainfall will be expect less variability under the two concentration path ways scenario . On the other hand the projected length of the growing season in the period 2050s and 2080s will be varies from 18-22 days at Sekota to 106 days at Abergele station under Rcp 4.5 and Rcp8.5 as predicted by the mean of ensemble GCMs. The average length of growing period in the study area will be ranges from 56 days at sekota to 74-77 days at Amdework station for the period of 2050s under low and high emission scenarios. Similarly for the period 2080s the mean length of the growing period will also ranges from 55-58 days at Sekota to 74 - 77 days at Amdework stations under Rcp4.5 and Rcp 8.5 scenario.

Based on Hare (1983) classification the probable coefficient of variation for the length of growing season will be high variable ($CV > 30\%$) at Sekota station for the period 2050s under Rcp8.5 and for the period 2080s under Rcp4.5 and Rcp8.5 emission scenario. Moreover at Sahla station the coefficient of variation also shows that the length of growing length will be expect extremely variable ($CV = 64\%$) under Rcp 4.5 while at Abergele highly variable ($CV = 34.5\%$) for

period 2080s for both stations. For the remaining stations less to moderate variable will be expect under both emission scenarios in the study area.

4.2.1.2. The projected number of rainy days variability

The future numbers of rainy days in the kiremt rain season projected by 20 ensembles mean of GCMs for the period 2050s and 2080s under low and high emission scenario in the study area is portrayed in (Table 4.13). The projected number of rainy days ranges from 20 days at Sekota to 86 days at Asketema station for the period 2050s and 2080s under both scenarios based on the result of GCMs model output. The probable average number of rainy days will be also varies from 40days at Sekota to 58 days at Sahla station over the next two century under Rcp4.5 and Rcp8.5 emission scenarios. The coefficient of variation for the future number of rainy days varies from 18.1percent to 26.2 percent at Amdework and Asketema stations respectively which indicates moderate variations per year. The result of coefficient of variation in all stations will be expect moderate year to year variations for the period 2050s and 2080s under low and high emission scenarios.

Table 4.13.Descriptive statistics of the projected number of rainy days in kiremt season at selected stations

Stations	RCP4.5						RCP8.5				
	Period	Min	Max	Mean	Sd	Cv	Min	Max	Mean	Sd	Cv
Amdework	2050s	31	85	65	11.7	18.1	31	85	65	11.7	18.1
	2080s	30	85	65	11.8	18.2	31	85	65	11.7	18.1
Asketema	2050s	24	86	55	13.7	24.9	24	86	52.9	13.6	25.6
	2080s	24	86	52.8	13.8	26.2	24	86	53.2	13.4	25.1
Sahla	2050s	40	74	58.8	9.5	16.2	40	74	58.8	9.5	16.2
	2080s	40	74	58.8	9.5	16.2	40	74	58.8	9.5	16.2
Sekota	2050s	20	59	39.8	8.6	21.7	20	59	40.3	8.6	21.3
	2080s	20	59	40.3	8.5	21	20	59	39.6	8.8	22.2
Tisiska	2050s	30	71	49.9	10.8	21.6	30	71	50.2	10.4	20.8
	2080s	30	71	50.3	10.3	20.5	30	71	50.1	10.5	20.9
Abergele	2050s	37	72	52.1	9.7	18.7	37	72	52	9.7	18.7
	2080s	37	72	52.1	9.7	18.7	37	72	52	9.7	18.7

4.2.1.3. The future number of dry days in the mid and end-century

The projected minimum number of dry days will be 36 days at Asketema whereas the maximum will be expect 102days at Sekota stations for the period 2050s and 2080s under Rcp 4.5 and Rcp8.5. The average number of dry days will be varies from 57 days at Amdework to 82 days at Sekota stations over the next two century under both scenarios. The probable coefficient of variation will be expect less to moderate variations at all stations for the study period(Table 4.14) .

Table 4.14.Descriptive statistics of the projected number of dry days in kiremt season at selected stations

Stations	RCP4.5						RCP8.5				
	Period	Min	Max	Mean	Sd	Cv	Min	Max	Mean	Sd	Cv
Amdework	2050s	37	91	57.3	11.7	20.4	37	91	57	11.7	20.4
	2080s	37	92	57.4	11.8	20.5	37	91	57.3	11.7	20.4
Asketema	2050s	36	98	69	13.6	19.7	36	98	69	13.6	19.7
	2080s	36	98	69.2	13.8	20	36	98	68.7	13.3	19.3
Sahla	2050s	48	82	63.2	9.5	15	48	82	63.2	9.5	15
	2080s	48	82	63.2	9.5	15	48	82	63.2	9.5	15
Sekota	2050s	63	102	82.2	8.6	10.5	63	102	81.7	8.6	10.5
	2080s	63	102	81.7	8.5	10.4	63	102	82.3	8.7	10.6
Tisiska	2050s	51	92	71.9	10.6	14.8	51	92	71.8	10.4	14.5
	2080s	51	92	71.7	10.3	14.4	51	92	71.8	10.5	14.6
Abergele	2050s	50	85	70	9.7	13.9	50	85	70	9.7	13.9
	2080s	50	85	70	9.7	13.9	50	85	70	9.7	13.9

4.2.1.4. The number of heavy rainfall in the future mid and end-century

The future average number of heavy rainfall ranges from 3.1 to 10.3 days by 2050s and 2.8 to 10.8 days by 2080s at Abergele and Amdework areas respectively under Rcp4.5 while under Rcp8.5 the expected average number of heavy rainfall will be ranges from 3.8 at Abergele and Sahla to 11.6 days at Amdework station by 2050s and 3.8 at Sahla to 12.5 days at Amdework by 2080s.The projected coefficient of variation in all stations revealed that extremely variable for both scenarios. This implies that the future heavy rainfall will be unreliable and un predictable.

Table 4.15 Descriptive statistics of the projected number of heavy rainfall in kiremt season at selected stations

Stations	RCP4.5						RCP8.5				
	Period	Min	Max	Mean	Sd	Cv	Min	Max	Mean	Sd	Cv
Amdework	2050s	1	28	10.3	6.7	65.1	1	35	11.6	7.9	68.1
	2080s	1	30	10.8	7.1	65.9	1	36	12.5	8.4	67.3
Asketema	2050s	0	31	6.5	7.6	115.6	0	31	7.1	8.1	114.3
	2080s	0	32	6.8	7.9	116.4	0	32	7.6	8.3	109.5
Sahla	2050s	0	9	3.4	2.5	75.4	0	10	3.8	2.9	76.8
	2080s	0	9	3.5	2.6	75.7	0	10	3.8	2.9	78.2
Sekota	2050s	0	11	3.8	2.9	78.1	0	11	4.5	3.3	73.8
	2080s	0	11	4.3	3.1	73.1	0	11	4.9	3.6	73.9
Tisiska	2050s	0	11	3.7	2.8	75.2	0	13	4.5	3.1	69.2
	2080s	0	11	3.7	2.8	74.4	0	13	4.8	3.2	67.2
Abergele	2050s	0	8	3.1	2.2	68.9	0	10	3.8	2.7	70
	2080s	0	8	2.8	1.9	70.8	0	13	4.1	3.03	73.4

4.2.1.5. The projected rainfall intensity for the mid and end century

The future rainfall intensity in the study area will be ranges from 5.1 mm/day at Sekota to 19.6mm/day at Amdework station based on the GCMs model out put under the Rcp4.5 emission scenario. Similarly the probable kiremt rainfall intensity will varies from 5.3 mm per day at Sekota to 27.1 mm/day at Asketema station from the ensemble mean of GCMs under high emission scenario (Rcp8.5).Based on Hare (2003) classification the coefficient of variation will be high which will be varies from 17% at Sahla to 38% at Asketema station under Rcp4.5 and Rcp8.5 scenarios (Table 4.16).

Table 4.16.Descriptive statistics of the projected rainfall intensity in kiremt season at selected stations

Stations	RCP4.5						RCP8.5				
	Period	Min	Max	Mean	Sd	Cv	Min	Max	Mean	Sd	Cv
Amdework	2050s	7.5	19.4	11.2	2.8	25	7.8	20.1	11.7	2.9	25
	2080s	7.6	19.6	11.3	2.8	25	8	21	12	3.1	25
Asketema	2050s	7	24	10.8	4	37	7.3	25.9	11.3	4.3	37
	2080s	7.2	24.7	11.5	4.3	37	7.3	27.1	11.8	4.9	38
Sahla	2050s	6.1	13	8.8	1.5	17	6.4	13.5	9.1	1.5	17
	2080s	6.1	13.1	8.8	1.5	17	6.2	13.8	9.2	1.6	17
Sekota	2050s	5.1	17.6	10.1	2.8	27	5.3	14.5	10.1	2.4	23
	2080s	5.5	14.5	10.1	2.3	22	5.5	14.8	10.6	2.5	23
Tisiska	2050s	5.8	17.3	9.2	2.3	25	6.2	13.7	9.4	1.8	19
	2080s	5.9	13	8.9	1.7	18	6.3	13.9	9.7	1.9	20
Abergele	2050s	6.4	13.2	8.8	1.7	19	6.5	13.7	9.2	1.8	19
	2080s	6.3	13.1	8.8	1.7	19	6.6	14	9.3	1.8	19

4.2.1.6. Future precipitation trends

Projected trends of annual and seasonal rain fall totals in the mid and end-century

Based on the result of Mann-kendall's trend test future trends of annual and kiremt rain fall totals by 2050s and 2080s under Rcp4.5 and 8.5 emission scenario projected by ensemble mean of 20 selected GCMs is shown in (Table4.17&4.18).The projected annual rainfall shows that statistically significant increasing trend at Amdework and Asketema stations by a factor of 14-15 and 12-13 mm per year respectively while at sahla station a non-significant increasing trend will be expect by a rate of 1.6-1.7 mm per year conversely a non-significant decreasing trend will be expect at Sekota ,Tisiska and Abergele stations by 1.1-1.2 , 1-1.3 and 0.8-0.9 mm per year respectively for the period 2050s under low and high emission scenario(Rcp4.5&8.5)(Table4.17).

Similarly, the probable annual rainfall for the period 2080s shows that statistically significant increasing trend at Amdework and Asketema stations by the rate of 14 and 12-14 mm per year respectively. Conversely a non-significant decreasing trend will be expect at Sekota , Tisiska and

Abergele stations by a factor of 1.9-2.4 , 1.3-1.8 and 1-1.1 mm per year respectively under Rcp4.5 and Rcp8.5(Table 4.18).At the seasonal level, the future kiremt rainfall for the period 2050s shows that statistically significant increasing trend at Amdework and Asketema stations by a factor of 12.3-12.9 and 12-15 mm per year respectively and also anon-significant increasing trend will be expect at Sahla , Sekota and Abergele stations by a rate of 1.1-1.2 , 4.3-4.7 and 0.9-1.2mm per year respectively. Conversely a non-significant decreasing trend will be occur at Tisiska station by a factor of 1.8-1.9 mm per year for the period 2050s under the two emission scenario (Table4.17). Moreover the projected kiremt rainfall shows that non-significant increasing trends at all stations for the period 2080s under both scenarios (Rcp4.5&Rcp8.5) in (Table 4.18).On the other hand the projected belg rainfall amount shows that a non-significant increasing trend at Amdework and Tisiska stations conversely anon-significant decreasing trend will be expect for the remaining stations for both 2050s and 2080s under RCP4.5 and RCP8.5 scenario.

Table 4.17.Trends of projected annual and seasonal (kiremt&belg) rainfall totals for the period2050s under Rcp4.5 and Rcp8.5 emission scenario at the selected stations.

Stations	Emission Scenarios	Annual			Kiremt			Belg		
		ZMK	Q	p-value	ZMK	Q	p-value	ZMK	Q	p-value
Amdework	RCP4.5	0.338	14.1	0.008 *	0.319	12.3	0.013 *	0.167	1.9	0.201**
	RCP8.5	0.338	15.1	0.008*	0.319	12.9	0.013 *	0.163	1.9	0.214**
Asketema	RCP4.5	0.338	12.6	0.008 *	0.398	15.3	0.002 *	-0.224	-2.2	0.086**
	RCP8.5	0.379	13.3	0.003 *	0.062	12	0.646 **	-0.22	-2.1	0.093**
Sahla	RCP4.5	0.089	1.7	0.501 **	0.067	1.1	0.621 **	-0.11	-0.35	0.382**
	RCP8.5	0.099	1.6	0.457 **	0.062	1.2	0.646 **	-0.11	-0.3	0.422**
Sekota	RCP4.5	-0.053	-1.1	0.697 **	0.255	4.7	0.059 **	-0.133	-2.9	0.309**
	RCP8.5	-0.053	-1.2	0.6974**	0.246	4.3	0.058**	-0.143	-3	0.276**
Tisiska	RCP4.5	-0.057	-1.0	0.672 **	-0.053	-1.8	0.697 **	0.037	0.3	0.789**
	RCP8.5	-0.048	-1.3	0.724 **	-0.067	-1.9	0.621 **	0.04	0.2	0.762**
Abergele	RCP4.5	-0.054	-0.9	0.686**	0.062	0.9	0.637**	-0.14	-0.64	0.276**
	RCP8.5	-0.049	-0.8	0.711**	0.062	1.2	0.637**	-0.14	-0.61	0.247**

Table 4.18: Trends of projected annual and seasonal (kiremt& belg) rainfall totals for the period 2080s under RCP4.5 and RCP8.5 emission scenario at selected stations.

Stations	Emission Scenarios	Annual			Kiremt			Belg		
		ZMK	Q	p-value	ZMK	Q	p-value	ZMK	Q	p-value
Amdework	RCP4.5	0.35	14.7	0.007*	0.31	12.5	0.016 *	0.177	1.6	0.175**
	RCP8.5	0.35	14.9	0.006 *	0.31	13.0	0.014 *	0.14	1.6	0.288**
Asketema	RCP4.5	0.32	12.8	0.014*	0.44	17.7	0.001*	-0.21	-2.1	0.116**
	RCP8.5	0.38	14.4	0.004 *	0.40	17.2	0.002*	-0.215	-2.2	0.100**
Sahla	RCP4.5	0.09	1.8	0.479 **	0.06	1.1	0.646 **	-0.11	-0.4	0.382**
	RCP8.5	0.09	1.7	0.457**	0.08	1.3	0.548 **	-0.10	-0.34	0.44**
Sekota	RCP4.5	-0.07	-2.4	0.596**	0.26	4.5	0.049 *	-0.152	-2.8	0.246**
	RCP8.5	-0.07	-1.9	0.621 **	0.25	5.1	0.058 **	-0.156	-3.3	0.232**
Tisiska	RCP4.5	-0.06	-1.3	0.646 **	0.26	4.5	0.049 **	0.032	0.13	0.816**
	RCP8.5	-0.08	-1.8	0.548**	0.25	5.1	0.058 **	0.046	0.1	0.734**
Abergele	RCP4.5	-0.054	-1	0.686**	0.045	0.7	0.736**	-0.145	-0.6	0.261**
	RCP8.5	-0.045	-1.1	0.736**	0.045	0.6	0.736**	-0.141	-0.7	0.276**

Based on the model output the projected trends of onset date, cessation date and length of the growing season for the main rainy season (June-September) over the next two periods (2050s and 2080s) under Rcp4.5 and Rcp8.5 is depicted in (Table 4.19). The future onset date shows that a non-significant increasing trend at Sahla, Sekota, Tisiska and Abergele stations by a factor of 1, 2, 3 and 3 days per decade respectively for the period 2050s and 2080s under low and high emission scenarios. Conversely, the projected onset date is showing negative (decrease) trends in the future at Amdework and Asketema stations by a rate of 4, 7-9 days per decade respectively in the study period. However, the result of Mann-Kendall's trend test shows non-significant at Amdework, whereas significant trends at Asketema station. On the other hand, the future cessation date will be expected to show significant increasing trends at Amdework and Sahla stations by a factor of 0.5 and 0.1-0.3 days per year respectively by 2050s and 2080s under the two scenarios. A non-significant increasing trend of cessation date will be expected at Asketema and Abergele stations by a rate of 0.1 and 0.3 days per year.

Moreover at Sekota station the cessation date will be expect a non- significant increasing trends for the period 2050s and 2080s under Rcp8.5 while non –significant decreasing and increasing trend for the period 2050s and 2080s respectively under Rcp4.5. conversely at Tisiska station the projected trends of end date showed a decreasing trend by a factor of 0.1-0.2 days per decade. The future length of growing season at Amdework and Asketema stations will be expect a significant increasing trends by a factor of 10 and 7-9 days per decade respectively while at Sahla station the length of growing period revealed that non-significant increasing trends by a rate of 0.4-7 days per decade based on the selected GCMs out put under the lower and higher emission scenarios for the period 2050s and 2080s.

Table 4.19.Trends of the projected onset date, cessation date and length of growing period during kiremt season at six stations for the period 2050s and 2080s

Stations	Variables	Rcp4.5						Rcp8.5					
		2050s			2080s			2050s			2080s		
		Zmk	Q	Pvalue	Zmk	Q	Pvalue	Zmk	Q	Pvalue	Zmk	Q	Pvalue
Amdework	SOS	-0.20	-0.4	0.12**	-0.20	-0.4	0.12**	-0.29	0.6	0.03*	-0.24	-0.4	0.074**
	EOS	0.32	0.5	0.02*	0.32	0.5	0.01*	0.31	0.5	0.02*	0.33	0.5	0.01*
	LGP	0.31	1	0.02*	0.32	1	0.01*	0.40	1	0.002*	0.38	1	0.004*
Asketema	SOS	-0.38	-0.7	0.004*	-0.38	-0.7	0.004*	-0.37	-0.8	0.005*	-0.47	-0.9	0.0003*
	EOS	0.12	0.1	0.39**	0.09	0.1	0.49**	0.09	0.1	0.47**	0.06	0.1	0.67**
	LGP	0.28	0.8	0.03*	0.27	0.7	0.04*	0.27	0.7	0.04*	0.36	0.9	0.01*
Sahla	SOS	0.12	0.13	0.38**	0.12	0.13	0.381**	0.10	0.13	0.44**	0.12	0.13	0.35**
	EOS	0.30	0.2	0.03*	0.29	0.1	0.03*	0.30	0.1	0.03*	0.32	0.3	0.02*
	LGP	0.03	0.04	0.80**	0.03	0.1	0.80**	0.08	0.2	0.54**	0.34	0.7	0.01*
Sekota	SOS	0.14	0.2	0.29**	0.07	0.2	0.60**	0.09	0.2	0.49**	0.01	0.1	0.93**
	EOS	-0.01	-0.02	0.95**	0.04	0.02	0.77**	0.05	0.02	0.71**	0.03	0.01	0.82**
	LGP	-0.13	-0.2	0.32**	-0.06	-0.1	0.65**	-0.06	-0.1	0.64**	0.06	0.1	0.67**
Tisiska	SOS	0.11	0.3	0.40**	0.11	0.3	0.40**	0.17	0.3	0.19**	0.17	0.3	0.20**
	EOS	-0.13	-0.2	0.34**	-0.09	-0.11	0.49**	-0.08	-0.1	0.54**	-0.12	-0.14	0.40**
	LGP	-0.20	-0.5	0.12**	-0.17	-0.5	0.19**	-0.19	-0.5	0.13**	-0.17	-0.4	0.21**
Abergele	SOS	0.148	0.32	0.254**	0.152	0.35	0.24**	0.15	0.4	0.25**	0.25	0.4	0.05**
	EOS	0.15	0.3	0.253**	0.14	0.3	0.268**	0.16	0.3	0.23**	0.15	0.3	0.239**
	LGP	0.01	0.04	0.959**	-0.02	-0.05	0.919**	-0.05	-0.2	0.68**	-0.06	-0.2	0.638**

Trends of the future number of rainy and dry days for the mid and end century

The projected average number of rainy days per year has been significantly increased at Amdework and Asketema stations by a factor of 6 and 2-3 days per decade respectively for the period 2050s and 2080s under Rcp4.5 and Rcp8.5 (Table 4.20) .Similarly anon-significant increasing trends will be expect by a factor of 4 and 2 days per decade at Sahla and Sekota stations respectively .Conversely anon –significant decreasing trends will be expect at Tisiska and Abergele stations. Moreover the future average number of dry days have been increased by 6, 2, 4 and 1-2 days per decade at Amdework ,Asketema,Sahla and Sekota stations respectively .However the probability value of dry days indicates significant trends at Amdework and Sahla stations where as non-significant trends at Asketema and Sekota stations conversely the number of dry days shows that a non-significant decreasing trends will be expect at Tisiska and Abergele stations by 3 days per decade for both stations over the next two century(2050s &2080s) under Rcp4.5 and Rcp8.5.

Table 4.20.Trends of the projected number of rainy and dry days during kiremt season at six stations for the period 2050s and 2080s

Stations	Variables	Rcp4.5						Rcp8.5					
		2050s			2080s			2050s			2080s		
		Zmk	Q	Pvalue	Zmk	Q	Pvalue	Zmk	Q	Pvalue	Zmk	Q	Pvalue
Amdework	NRD	0.339	0.6	0.01*	0.339	0.6	0.01*	0.339	0.6	0.01*	0.339	0.6	0.01*
	NDD	-0.339	-0.6	0.01*	-0.339	-0.6	0.01*	-0.339	-0.6	0.01*	-0.339	-0.6	0.01*
Asketema	NRD	0.058	0.2	0.67**	0.093	0.2	0.49**	0.111	0.3	0.401**	0.10	0.2	0.45**
	NDD	-0.058	-0.2	0.67**	-0.093	-0.2	0.49**	-0.111	-0.3	0.40**	-0.10	-0.2	0.45**
Sahla	NRD	0.263	0.4	0.04*	0.263	0.4	0.04*	0.263	0.4	0.045**	0.263	0.4	0.04*
	NDD	-0.263	-0.4	0.04*	-0.263	-0.4	0.04*	-0.263	-0.4	0.045*	-0.263	-0.4	0.04*
Sekota	NRD	0.086	0.2	0.52**	0.069	0.1	0.60**	0.098	0.2	0.464**	0.093	0.2	0.49**
	NDD	-0.086	-0.2	0.52**	-0.069	-0.1	0.60**	-0.098	-0.6	0.464**	-0.091	-0.2	0.49**
Tisiska	NRD	-0.209	-0.4	0.11**	-0.212	-0.4	0.11**	-0.212	-0.4	0.108**	-0.202	-0.33	0.12**
	NDD	0.205	0.4	0.12**	0.212	0.4	0.11**	0.212	0.4	0.108**	0.202	0.3	0.12**
Abergele	NRD	-0.151	-0.3	0.25**	-0.078	-0.1	0.55**	-0.151	-0.3	0.247**	-0.151	-0.3	0.25**
	NDD	0.151	0.3	0.25**	0.151	0.3	0.25**	0.151	0.3	0.247**	0.151	0.3	0.25**

Trends of the number of heavy rainfall and intensity of rainfall for mid and end-century

The projected average number of heavy rainfall has been increased by 3-4 days, 2 days and 1-2 days per decade in the future at Amdework, Asketema and Sekota stations respectively for the period 2050s and 2080s under Rcp4.5 and Rcp8.5 emission scenarios based on climate models output (Table 4.21). However the probability value of the future number of heavy rainfall result indicates that non-significant increasing trend at Sekota whereas at Amdework and Asketema stations statistically significant trends will be expect. Conversely the estimated number of heavy rainfall shows that statistically non-significant decreasing trends at Tisiska and Abergele stations by a factor of 0.3-0.5 days and 0.2-0.5 days per decade respectively while at Sahla station significant decreasing trend will be expect by 1 days per decade for next two century (mid and end century). On the other hand the simple daily intensity index shows that the projected rainfall intensity will be statistically non-significant increasing trends by a factor of 0.7mm/day, 0.9-1.1mm/day and 0.6mm/day at Amdework, Sekota and Abergele stations respectively while at Abergele station significant increasing will be expect by a factor of 1.6-2.2 mm/day for the period 2050s and 2080s under low and high emission scenarios.

Table 4. 21. Trends of the projected number of heavy rainfall and intensity of rainfall during kiremt season at six stations for the period 2050s and 2080s

Stations	Variables	Rcp4.5						Rcp8.5					
		2050s			2080s			2050s			2080s		
		Zmk	Q	Pvalue	Zmk	Q	Pvalue	Zmk	Q	Pvalue	Zmk	Q	Pvalue
Amdework	R20	0.29	0.3	0.03*	0.29	0.3	0.03*	0.28	0.3	0.03*	0.31	0.4	0.02*
	SDII	0.19	0.07	0.13**	0.19	0.07	0.14**	0.2	0.07	0.13**	0.17	0.07	0.20**
Asketema	R20	0.23	0.25	0.08**	0.224	0.23	0.09**	0.23	0.2	0.08**	0.19	0.2	0.161**
	SDII	0.39	0.16	0.002*	0.42	0.22	0.001*	0.39	0.17	0.002*	0.43	0.21	0.008*
Sahla	R20	-0.31	-0.13	0.02*	-0.302	-0.13	0.03*	-0.27	-0.12	0.04*	-0.27	-0.1	0.043*
	SDII	-0.18	-0.04	0.17**	-0.19	-0.04	0.14**	-0.18	-0.04	0.18**	-0.19	-0.04	0.14**
Sekota	R20	0.26	0.14	0.04*	0.284	0.15	0.04*	0.27	0.15	0.04*	0.27	0.2	0.042*
	SDII	0.24	0.11	0.07**	0.25	0.11	0.05**	0.22	0.09	0.08**	0.23	0.11	0.08**
Tisiska	R20	-0.13	-0.04	0.36**	-0.106	-0.04	0.45**	-0.07	-0.03	0.61**	-0.09	-0.05	0.506**
	SDII	0.03	0.01	0.92**	-0.02	-0.01	0.92**	-0.05	-0.02	0.72**	0.02	0.01	0.91**
Abergele	R20	-0.17	-0.04	0.21**	-0.179	-0.05	0.18**	-0.05	-0.02	0.72**	-0.11	-0.04	0.401**
	SDII	0.22	0.06	0.09**	0.23	0.06	0.07**	0.21	0.06	0.10**	0.20	0.06	0.12**

R20 indicates that number of heavy rain fall/annual count of days when rainfall $\geq 20\text{mm}$ SDII indicates simple daily intensity index/total annual rainfall per number of rainy days ** indicates non-significance value when p-value $\geq 5\%$ while * indicates significance value when p-value $< 0.05 (5\%)$. ZMK indicates Mann-Kendal trend test/upward or down ward its trend Q indicates sen's slope the change per year/decade

4.2.2. The Future temperature variability

4.2.2.1. The future temperature variability and trends in the mid and end century

The projected annual maximum temperature is expected to be within the range of 22.9°C to 36.5°C under Rcp4.5 and 23.6°C to 38.3°C under Rcp8.5 scenario at Amdework and Tisiska stations for the period 2050s and 2080s respectively depending on emission scenarios and climate models (Appendix Table 11). The projected coefficient of variation shows that less year to year variation of the annual maximum temperature in all stations under Rcp4.5 and Rcp8.5 scenarios for the period 2050s and 2080s. On the other hand projections show that the annual minimum temperature in the study area varies between 10.5°C to 22.4°C under low emission scenario and 11.2°C to 24.5°C under high emission scenario at Amdework and Abergele stations for the period 2050s and 2080s respectively (Appendix Table 12). There is also less inter-annual minimum temperature variations based on Hare (2003) classification for the next two century depending emission scenarios and Global Climate Models in the study area (Appendix Table 12).

The average annual temperature in the study area is projected to be within the range of 17.1°C to 28.8°C under Rcp4.5 and 17.8°C to 30.7°C under Rcp8.5 scenarios at Amdework, Tsiska and Abergele stations for the period 2050s and 2080s respectively (Table 4.22). The projected coefficient of variation in the study area will be expected that little inter-annual fluctuations of mean annual temperature for the next two future climatological periods namely mid and end century (2050s&2080s).

Table 4.22. Descriptive statistics of the projected mean annual temperature in the study area for the period 2050s and 2080s under Rcp4.5 and Rcp8.5.

Stations	RCP4.5						RCP8.5				
	Period	Min	Max	Mean	Sd	Cv	Min	Max	Mean	Sd	Cv
Amdework	2050s	17.1	20.7	18.5	0.78	4.2	17.8	21.3	19.1	0.75	3.9
	2080s	17.7	21.3	19.1	0.76	4	19.6	23.1	20.9	0.75	3.6
Asketema	2050s	18.3	22.8	19.4	0.87	4.5	19.1	23.6	20.1	0.88	4.4
	2080s	18.9	23.4	20	0.87	4.4	20.8	25.3	21.9	0.87	4
Sahla	2050s	21.3	27.9	23.1	1.26	5.5	22.1	28.6	23.8	1.25	5.3
	2080s	22	28.5	23.6	1.25	5.3	23.9	30.4	25.6	1.25	4.9
Sekota	2050s	19.8	23.6	21.2	0.85	4	18.8	23.7	21.7	0.94	4.3
	2080s	20.4	23.6	21.6	0.75	3.5	19.3	25.5	23.2	1.37	5.9
Tisiska	2050s	20.2	28.3	22.6	2.03	9	20.8	28.9	23.3	1.99	8.5
	2080s	21	28.8	23.2	2.02	8.7	21	30.7	24.9	2.1	8.4
Abergele	2050s	20.8	28.3	22.5	1.6	6.9	21.5	28.9	23.1	1.5	6.7
	2080s	21.3	28.8	22.9	1.6	6.8	23.2	30.7	24.9	1.6	6.3

4.2.2.2. The future temperature trends for mid and end-century

Projections show that increasing trends of the future annual maximum and minimum temperature at all stations depending on emission scenarios and Global Climate Models (GCMs). However, the result of the Mann-kendall's trend test indicates that the probability of annual maximum temperature trend will be non-significant increasing trends for the period 2050s and 2080s under Rcp4.5 and 8.5. The Mann-kendall's trend test result shows that the expected average temperature will be increasing tendency at all stations over the next two century (mid and end century) based on the selected scenarios. However, the probability value shows that non-significant increasing trends at Asketema stations only for the two Rcps (Table 4.23).

Table 4.23.Trends of the projected annual maximum, minimum and average temperature at six stations for the period 2050s and 2080s under both scenarios.

Stations		Rcp4.5						Rcp8.5					
		2050s			2080s			2050s			2080s		
		Zmk	Q	Pvalue	Zmk	Q	Pvalue	Zmk	Q	Pvalue	Zmk	Q	Pvalue
		temperature											
Amdework	Maximum	0.36	0.04	0.005*	0.39	0.04	0.002*	0.46	0.05	0.002*	0.38	0.04	0.003*
	Minimum	0.49	0.06	0.001*	0.48	0.06	0.001*	0.54	0.06	0.001*	0.51	0.06	0.0001*
	Average	0.503	0.1	0.001*	0.522	0.1	0.001*	0.54	0.1	0.001*	0.54	0.1	0.001*
Asketema	Maximum	0.21	0.02	0.10**	0.14	0.01	0.272**	0.21	0.02	0.112**	0.16	0.01	0.228**
	Minimum	0.35	0.03	0.006*	0.37	0.04	0.003*	0.35	0.03	0.006*	0.36	0.03	0.005*
	Average	0.19	0.02	0.14**	0.21	0.02	0.12**	0.21	0.02	0.12**	0.22	0.02	0.09**
Sahla	Maximum	0.41	0.04	0.001*	0.39	0.04	0.002*	0.41	0.04	0.001*	0.56	0.06	0.001*
	Minimum	0.54	0.08	0.001*	0.53	0.08	0.001*	0.52	0.08	0.001*	0.53	0.08	0.001*
	Average	0.56	0.1	0.001*	0.55	0.1	0.001*	0.55	0.05	0.001*	0.56	0.1	0.001*
Sekota	Maximum	0.33	0.06	0.009*	0.28	0.05	0.032*	0.34	0.06	0.007*	0.24	0.04	0.039*
	Minimum	0.51	0.07	0.001*	0.44	0.07	0.001*	0.42	0.06	0.001*	0.29	0.04	0.02*
	Average	0.39	0.05	0.002*	0.26	0.03	0.045*	0.27	0.04	0.038*	0.131	0.03	0.321**
Tisiska	Maximum	0.45	0.09	0.003*	0.45	0.1	0.0003*	0.37	0.01	0.004*	0.48	0.1	0.0001*
	Minimum	0.46	0.05	0.002*	0.49	0.06	0.001*	0.48	0.06	0.001*	0.40	0.05	0.002*
	Average	0.48	0.09	0.001*	0.47	0.08	0.002	0.39	0.07	0.002*	0.49	0.07	0.001*
Abergele	Maximum	0.273	0.03	0.032*	0.312	0.03	0.014*	0.29	0.03	0.022*	0.303	0.03	0.016*
	Minimum	0.557	0.06	0.001*	0.548	0.06	0.001*	0.54	0.06	0.001*	0.55	0.06	0.001*
	Average	0.49	0.04	0.001*	0.49	0.05	0.001*	0.49	0.04	0.001*	0.49	0.04	0.001*

4.2.3. The projected rainfall changes from the baseline period for mid and end century

The percentage changes of the projected annual and seasonal rainfall amount from the base period (1986-2016) in the study area is shown in (Table 4.24).As compared to the base period the mean annual and seasonal rainfall amount is expected to increase or decrease in the study area varies with locations for the period 2050s and 2080s depending the emission scenarios and climate model out puts. The probable mean annual rainfall amount expected to decrease at Amdework, Asketema, Sahla, Sekota Tisiska and Abergele stations by 0.69%,5.5%,4%,2.4% ,2.7%and 1.6% respectively based on Rcp4.5 for the period 2050s (Table 4.24).

Similarly by 2080s the amount of annual rainfall expected to decrease in all stations except sekota under Rcp 4.5. In line with this study conducted by Ayalew et al.,(2012) indicated that by the years 2080s the amount of annual rainfall and number of rainy days will decrease in the Amhara National Regional State, Ethiopia.

On the other hand the amount of annual rainfall expected to increase at Amdework, Sahla, Sekota, Tiiska and Abergele stations by 3.1%, 0.2%, 0.6%, 2.4% and 2.1% respectively for the period 2050s under high emission scenario (Rcp8.5). Likewise based on Rcp8.5 scenario for the period 2080s the expected annual rainfall will be increase in all stations.

The projected changes in precipitation for main and small rainy season over the study area relative to the historical (reference period 1986-2016) vary between the two emission scenarios (Rcps). The expected kiremt rainfall will be decreased in all stations for the mid-century under Rcp4.5. Similarly for the end century (2080s) the probable rainfall amount for the kiremt season will be decreased from the base period in all stations except Amdework based on Rcp4.5 scenario. In Ethiopia, a study conducted by Arndt et al.,(2011) showed that Kiremt and belg seasons' rainfall is decreasing by 20% and 5-6% respectively for the period 2080s. Moreover the estimated rainfall will be decreased during kiremt season at Amdework, Asketema, Sahla and Sekota by 1.3%, 2%, 3.9% and 2.1% respectively while at Tiiska and Abergele stations the expected kiremt rainfall will be increased by 2.1% and 1.9% respectively in the mid-century under high emission scenario (Rcp8.5). Likewise the expected kiremt rainfall will be increased by 5.6%, 0.3%, 3.6% and 3.5% at Amdework, Asketema, Tiiska and Abergele stations respectively whereas at Sahla and Sekota stations will expect increasing by 0.2% and 0.1% respectively for the period 2080s under Rcp8.5 scenario.

The Belg (February-May) seasonal rainfall change in the mid-century (2050s) will be increased in all stations except Asketema under both scenarios (Rcp4.5 & 8.5). Similarly for the end-century (2080s) under high emission scenario the projected belg rain fall will be increased in all stations except Asketema. On the other hand estimated rain fall will be decreased at Asketema, Sekota, Tiiska and Abergele stations by 9.9%, 3.6%, 2.3% and 2.6% respectively while the expected belg rain fall will be increased at Amdework and Sahla stations by 0.1% and 0.8% respectively for the period 2080s under Rcp4.5 emission scenario.

Table 4.24: Comparisons of observed and projected mean annual and kiremt rainfall amount in percent in the study area.

Station name	Annual				Kiremt				Belg			
	2050s		2080s		2050s		2080s		2050s		2080s	
	Rcp	Rcp	Rcp	Rcp	Rcp	Rcp	Rcp	Rcp	Rcp	Rcp	Rcp	Rcp
	4.5	8.5	4.5	8.5	4.5	8.5	4.5	8.5	4.5	8.5	4.5	8.5
Amdework	-0.69	3.1	-0.1	6.9	-2	-1.3	2.6	5.6	7.5	4.1	0.1	6.3
Asketema	-5.5	1.7	-3.4	2.8	-6.9	-2	-3.2	0.3	-4.6	-4.8	-9.9	-1
Sahla	-4	0.2	-3.1	0.7	-4.5	-3.9	-0.3	-0.2	2.6	4.5	0.8	5.3
Sekota	-2.4	0.6	-0.27	6.3	-4.6	-2.1	-2.1	-0.1	1.4	1.8	-3.6	6.1
Tisiska	-2.7	2.4	-1.6	4.7	-3.6	2.1	-2.6	3.6	3.8	2.3	-2.3	4.3
Abergele	-1.6	2.1	-1.9	4.6	-2.1	1.9	-2.3	3.5	4.6	3.1	-2.6	7.9
Average	-2.4	1.6	-1.2	4.9	-2.7	0.79	-1.7	2.8	2.6	1.8	-2.9	4.8

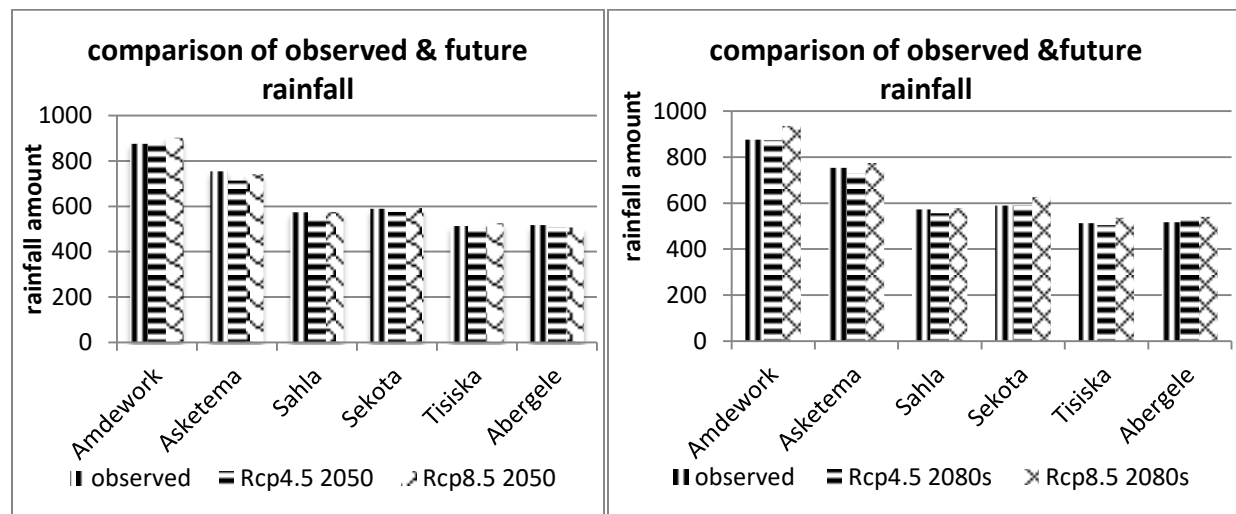


Figure 4.13. Comparison of the projected and observed rainfall

4.2.4. Projected changes of rainfall characteristics relative to the baseline period

The comparisons of observed rainfall characteristics such as onset date, cessation date, length of growing period, number of rain day and number of dry day with projected future rainfall characteristics is depicted in (Table 4.25).

The GCM projections suggest that the onset date of the future kiremt growing season will be decline by 0.54 - 2.2% at Amdework and 0.52 - 1.2% at Tisiska station from the base line period for the period 2050s and 2080s under Rcp 4.5 and 8.5 emission scenarios. The declining change on start of the rain season indicates that early entrance of the kiremt rainfall across the two stations by 2050s and 2080s. on the other hand the projected starting kiremt rainfall will be expect increasing percentage changes by 0 - 0.1.1% at Asketema , 0 - 1.1% at Sahla, 0.53 - 1.6% at Sekota and 0.53 - 1.1% at Abergele stations for the future period 2050s and 2080s with the two emission scenarios.

The projecting increasing onset date indicates that late onset of the kiremt rainfall for the future. Similarly the projected cessation date will be expect declining changes from the observed end date by 4.6 - 5.7% at Amdework, 4.6 - 5.4% at Asketema, 6.8 - 7.5% at Sahla, 4.5 - 5.6% at Sekota and 3.1 - 4.5% at Tisiska stations for the future period of 2050s and 2080s. The projected declining change in cessation date indicates that the end date of future kiremt growing season will terminate early to the mean end date of the base period.

The projected relatively high early cessation of the future kiremt growing season will have an effect on length of growing season by shortening the duration of growing season and this will affect rain-fed crop production. The percentage changes of the length of the growing period is projected by the ensemble GCM for medium and high emission scenario showing a decline of the length of growing season by 12 - 15.4% at Amdework, 16.1-18.6% at Asketema , 5.4 - 26.3% at Sahla, 19.8 - 23.9% at Sekota, and 11.6 - 14.7% at Tisiska stations for the mid and end century.

Results from the GCM ensemble out puts under the two Rcps during future period of 2050s and 2080s for the Amdework, Sahla and Tisiska stations revealed increasing percentage changes in the number of kiremt rainfall from past periods (1986 - 2016) while at Asketema and Sekota stations the projected number of rainfall to be declining from the reference period. Likewise the GCM projections suggest that increasing changes in the number of dry day in the kiremt season by 1.7% at Amdework, 2.9% at Asketema, 2.5% at Sekota and 1.4% at Abergele stations while decreasing changes will be expect at Sahla and Tisika by 3.2% and 2.7 % respectively for the future period 2050s and 2080s. The predicted increasing change in number of dry day indicates that in the future main rain season (Kiremt) rain fed crop production will face challenge of moisture stress in the study area by 2050s and 2080s.

Table 4.25. Projected percentage changes (%) of rainfall characteristics as compared to baseline period at the selected stations using an ensemble mean of eight GCMs for two representative concentration pathways.

Stations	RCP4.5						RCP8.5				
	Period	SOS	EOS	LGP	NRD	NDD	SOS	EOS	LGP	NRD	NDD
Amdework	2050s	-0.54	-5.7	-15.4	3.2	1.7	-2.2	-5.3	-12	3.2	1.7
	2080s	-0.54	-4.9	-15.4	3.2	1.7	-0.54	-4.6	-14.3	3.2	1.7
Asketema	2050s	0	-5.4	-18.6	-1.9	2.9	0	-4.9	-16.1	-5.6	2.9
	2080s	0.54	-4.9	-17.3	-3.8	2.9	1.1	-4.6	-17.3	-3.8	2.9
Sahla	2050s	0.52	-7.5	-26.3	3.4	-3.2	0	-7.5	-24.3	3.4	-3.2
	2080s	1.1	-7.2	-25.6	3.4	-3.2	0	-6.8	-5.4	3.4	-3.2
Sekota	2050s	0.53	-5.6	-22.5	-7.1	2.5	0.53	-5.2	-19.8	-4.7	2.5
	2080s	1.6	-4.9	-23.9	-4.7	2.5	1.6	-4.5	-22.5	-7.1	2.5
Tisiska	2050s	-1.1	-3.1	-14.7	0	-2.7	-1.2	-4.5	-11.6	2	-2.7
	2080s	-1.2	-4.2	-13.2	2	-2.7	-0.52	-3.7	-11.8	2	-2.7
Abergele	2050s	0.53	-0.2	-2.7	0	1.4	1.1	-0.2	0	0	1.4
	2080s	1.1	0.3	-4.1	0	1.4	1.1	0.3	0	0	1.4
Average	2050s	-0.01	-4.6	-16.7	-0.4	0.43	-0.29	-4.6	-13.9	-0.28	0.43
	2080s	0.43	-4.3	-16.6	0.02	0.43	0.46	-3.9	-11.9	-0.38	0.43

4.2.5. Projected temperature change from base line period

The projected maximum and minimum temperature changes in the selected stations relative to the baseline period (1986-2016) are shown in (Table 4.26). The result revealed that the maximum and minimum temperature have been increasing annually in all stations but the magnitude of change may depend on location of stations and emission scenarios. On average the annual maximum temperature will increase by 1.8 °C and 2.4 °C for the period 2050s under Rcp4.5 and Rcp8.5 scenarios respectively. Similarly the maximum temperature expected to be increased by 2.3 °C and 3.7 °C annually for the period 2080s under medium (Rcp4.5) and high emission scenario (Rcp8.5) respectively. Likewise the minimum temperature will be increased by 1.9 °C and 2.5 °C for the period 2050s under Rcp4.5 and Rcp8.5 emission scenarios respectively while for the period 2080s also will increase by 2.4 °C and 4.3 °C annually under medium and high

emission scenarios. The result also revealed that for most stations the magnitude of maximum and minimum temperature change will be higher under Rcp8.5 emission scenario than the medium one(Rcp4.5).Additionally the result revealed that temperature of the studied stations would increase with time and the warming is expected to be more for minimum temperature .Generally the maximum and minimum temperature have been increasing Consistently at all stations annually based on emission scenarios and Global Climate Models output.

Table 4.26.The projected annual maximum and minimum temperature changes (°C) from the reference period (baseline period) for the selected stations.

Station name	Maximum temperature change (°C)				Minimum temperature change(°C)			
	Mid-century		End- century		Mid-century		End –century	
	RCPs 4.5	RCPs8.5	RCPs4.5	RCPs8.5	RCPs4.5	RCPs8.5	RCPs4.5	RCPs8.5
Amdework	1.9	2.5	2.5	4.2	2	2.6	2.5	4.6
Asketema	1.9	2.3	2.3	4.1	1.9	2.6	2.4	4.6
Sahla	1.8	2.2	2.4	2.5	1.8	2.4	2.4	4.1
Sekota	1.6	2.2	2.1	3.1	2.1	2.6	2.3	4
Tisiska	1.7	2.3	2.2	3.9	1.6	2.2	2.1	4
Abergele	2.1	2.7	2.6	4.3	1.9	2.7	2.5	4.5
Average	1.8	2.4	2.3	3.7	1.9	2.5	2.4	4.3

The projected annual and seasonal average change of temperature in the mid-century (2040-2069) and end-century (2070-2099) as compared to the reference period (1986-2016) is depicted in (Table 4.27).The mean annual temperature will be increased by 2050s and 2080s in all stations under medium and high emission scenarios. Similarly the average temperature during kiremt(June-September) and belg(February-May) will be also increase over the next mid and end century in the study area. Generally, the study area under Rcp4.5 scenario annual average temperature is likely to rise by 1.9°C to 2.4°C in the 2050s and 2080s respectively. Likewise under Rcp8.5 annual average temperature is likely to rise by 2.8 to 4.1 by 2050s and 2080s respectively. Accordingly, the projected global average temperature is to be increase with 1.5°C to 5.4 °C (IPCC, 2014)

Table 4.27. Projected annual, belg and kiremt temperature changes (°C) as compared to baseline period in Waghenra Zone using an ensemble mean of eight GCMs for two representative concentration pathways.

Stations	RCP4.5				RCP8.5		
	Period	Annual	Kiremt	belg	Annual	Kiremt	Belg
Amdework	2050s	1.9	2	1.7	2.6	2.7	2.5
	2080s	2.5	2.6	2.3	4.3	4.5	4.2
Asketema	2050s	1.9	2.1	1.9	2.6	2.8	2.7
	2080s	2.5	2.7	2.5	4.3	4.7	4.4
Sahla	2050s	1.9	2	1.5	2.3	2.7	2.7
	2080s	2.5	2.6	2.2	3.2	4.6	4.5
Sekota	2050s	2	2.3	1.9	2.5	2.7	2.3
	2080s	2.3	2.6	2.2	3.9	4.2	3.5
Tisiska	2050s	1.6	1.6	1.5	4	2.3	2.1
	2080s	2.2	2.3	2	4.6	3.7	3.7
Abergele	2050s	2	2.1	1.8	2.6	2.8	2.5
	2080s	2.4	2.6	2.4	4.4	4.7	4.2
Average	2050s	1.9	2	1.7	2.8	2.7	2.5
	2080s	2.4	2.6	2.3	4.1	4.4	4.1

4.3. Rainfall, Temperature and crop production correlations

4.3.1. Variations and trends in crop production

Table 4.28. Summary of statistics of yield quintal/hectare (Qt/ha) of wheat and sorghum crops in the study area. The maximum value for wheat yield was ranging from 9.8 quintal per hectare at Abergele to 19.4 quintal per hectare at Amdework while the minimum values for wheat yield varied from 2.2 quintal per hectare at Tisiska to 7.5 quintal per hectare at Amdework (Table 4.118). Wheat has the lowest mean yield value 5.4 quintal per hectare at Tisiska whereas the highest wheat mean yield value 11.6 quintal per hectare at Amdework during the last decades. Based on Hare (1983) classification wheat productions show high year to year variations in all locations (CV>30%). On the other hand the minimum sorghum yield was 1.9 quintal per hectare

which was recorded at Tisiska while the maximum was 13.7 quintal per hectare at Amdework. Sorghum has the lowest mean yield value 6.5 quintal per hectare at Tisiska while the highest mean yield value was 8.9 quintal per hectare at Amdework. Sorghum production shows high year to year variations at Amdework, Sekota and Tisiska ($cv > 30\%$) whereas at Asketema, Sahla and Abergele moderate year to year variations ($cv < 30\%$). Out of the two cereal crops on average, sorghum has the lowest mean yield value 7.7 quintal per hectare while wheat has the highest mean yield value 8.2 quintal per hectare for the study area. Sorghum and wheat productions show high year-to-year variations based on the value of coefficient of variation ($CV > 30\%$) in the study area. The highest coefficient of variability of wheat and sorghum could be as a result of the joint effect by the variability in rainfall and temperature.

Table 4.28. Summary of statistics of yield (Qt/ha) of wheat and sorghum crops in the study area (2007-2016)

Stations	Wheat					Sorghum				
	Min	Max	Mean	SD	Cv	Min	Max	Mean	SD	Cv
Amdework	7.5	19.4	11.6	3.84	33.1	5.3	13.7	8.9	2.87	32.3
Asketema	5.3	15.8	10.3	3.04	29.5	4.6	13.4	8.25	2.34	28.4
Sahla	3.2	10.5	7.91	2.56	32.4	4.8	11.2	7.7	2.04	26.5
Sekota	4.3	13.6	7.24	2.95	40.7	3.9	13.4	7.49	3.28	43.8
Tisiska	2.2	10.8	5.37	2.97	55.4	1.9	10.4	6.51	2.69	41.4
Abergele	4	9.8	6.7	2.02	30.2	4.2	10.3	7.35	2.11	28.7
Average	4.4	13.3	8.2	2.9	36.9	4.1	12.1	7.7	2.6	33.5

4.3.2. Trends in crop production

Table (4.29): Showed the Man Kendall's trend test of Wheat and Sorghum yields result over the study period (2007-2016) in waghemra zone. According to the result in (Table 4.29) showed the yields of Wheat is decreasing trends by 0.02, 0.17, 0.29, 0.63 and 0.22 quintal per hectare at Amdework, Asketema, Sahla, Tisiska and Abergele respectively. However the result of the trend was significant at Tisiska only. While wheat yields showed a non-significant increasing trends by 0.43 quintal per hectare at Sekota.

Likewise sorghum production showed non-significant decreasing trends by 0.18, 0.38, 0.63 and 0.19 at Amdework, Sahla, Tisiska and Abergele quintal per hectare respectively. On the contrary sorghum yields were showed a non-significant increasing trends by a rate of 0.28 and 0.52 at

Asketema and Sekota quintal per hectare respectively. In general trend analysis indicates that the production of wheat and sorghum have been showing a decreasing trend per hectare over the period.

Table 4.29. Trends of Wheat and Sorghum yields in the study area for the period 2007-2016

Stations	Wheat			Sorghum		
	Kendall's	Sen's slope	p-value	Kendall's	Sen's slope	p-value
Amdework	-0.067	-0.02	0.862**	-0.156	-0.18	0.601**
Asketema	-0.15	-0.17	0.601**	0.289	0.28	0.291**
Sahla	-0.20	-0.29	0.484**	-0.33	-0.38	0.216**
Sekota	0.24	0.43	0.381**	0.20	0.52	0.484**
Tisiska	-0.556	-0.63	0.029*	-0.467	-0.63	0.073**
Abergele	-0.15	-0.22	0.601**	-0.289	-0.19	0.291**
Zonal level	-0.24	-0.32	0.38**	-0.16	-0.15	0.601**

*is statistically significant trend at 0.05 probability level while ** is non-significant change

4.3.3. Relationship between Rainfall Characteristics and crop Yield (Wheat Sorghum)

The correlation between rainfall characteristics and the selected crop production were computed and the result is presented in (Table 4.30). The kiremt rainfall amount had strong positive correlations with Wheat and Sorghum yields($r>0.8$) for all locations. This implies that increased rainfall amount also resulted in increased Wheat and Sorghum yields per hectare over the study area. Likewise the length of growing period also shows positive correlation with Wheat and Sorghum yields. This means that when the duration of the season becomes large the yields of Wheat and Sorghum increased. Conversely dates of onset had negative correlations with Wheat and Sorghum yields. This shows that as dates of onset increase (late onset) the yields of both Wheat and Sorghum decreases' for all locations. Moreover, the Wheat yields had positive correlations with cessation dates for all locations except at Sekota while that of Sorghum also shows positive correlations with cessation dates except at Sekota and Asketema areas. This implies that for positive correlations years with either late cassation tend to have more yields. Generally rainfall amount, number of rainy days and length of growing period shows strong positive correlations with both Wheat and Sorghum yields in the study area. This implies that the higher the amount of rainfall spread over the number of rain days with extended duration in a

year, the higher the yield of Wheat and Sorghum per hectare in the area. On the other hand dates of onset shows strong negative correlations with Wheat and Sorghum yields.

This implies as onset increase (late onset) the yields of Wheat and Sorghum decline while the onset becomes decrease (early onset) the yields tend to have more. On the other hand dates of cessation shows strong and weak positive relations with Wheat and Sorghum yields respectively.

Table 4.30: Correlation between production of crops and rainfall characteristics

District	Wheat					Sorghum				
	Rainfall	SOS	EOS	LGP	NRD	Rainfall	SOS	EOS	LGP	NRD
Amdework	0.92	-0.65	0.32	0.68	0.71	0.90	-0.68	0.33	0.75	0.63
Asketema	0.93	-0.15	0.06	0.61	0.40	0.84	-0.10	-0.54	0.27	0.32
Sahla	0.87	-0.38	0.83	0.34	0.09	0.95	-0.54	0.68	0.54	-0.08
Sekota	0.92	-0.55	-0.04	0.43	0.27	0.89	-0.54	-0.02	0.42	0.17
Tisiska	0.91	-0.53	0.87	0.74	0.82	0.94	-0.64	0.78	0.79	0.86
Abergele	0.94	-0.50	0.48	0.67	0.69	0.90	-0.26	0.49	0.44	0.69
Zonal level	0.87	-0.59	0.55	0.72	0.67	0.91	-0.53	0.32	0.57	0.59

SOS= start of the season, EOS=Ending of season, LGP=Length of Growing period, NRD=number of rainy days

4.3.4. Relationship between temperature and yields of Wheat and Sorghum

The correlation between minimum, maximum and mean temperature with yields of Wheat and Sorghum depicted in (Table4.31). The table revealed that both Sorghum and Wheat production showed negative correlation with minimum (night time), maximum (daytime) and mean temperature.

This suggests that as night time, daytime and average temperature increased production of wheat and sorghum declined. The study revealed that the temperature has a negative relationship with the yield of both wheat and sorghum, therefore, indicating that as temperature decreases, the yield of both wheat and sorghum increases. Increased temperature leads to increased evapotranspiration and affects water availability, which is very important in the process of photosynthesis (Dawyer et al., 2006).High temperature affects the chloroplasts where

photosynthesis takes place through generation of reactive oxygen species (Kreslavski et al., 2007). Generally, Pearson correlation analysis between mean maximum and minimum temperatures and crop production showed non-significant but negative relationships. The increase in the maximum and minimum temperatures results in high evapotranspiration which results in water stress.

Thus increase in mean temperature and its variability has been a contributor to the decline of both crops production.

Table 4.31: Correlation between production of crops and temperature at the selected areas

Stations	Wheat	Sorghum	Wheat	Sorghum	Wheat	Sorghum
	Mean temperature		Maximum temperature		Minimum temperature	
Amdework	-0.58	-0.27	-0.09	-0.12	-0.11	-0.41
Asketema	-0.48	0.17	-0.48	-0.16	-0.44	-0.17
Sahla	-0.45	-0.36	-0.49	-0.39	-0.38	-0.28
Sekota	-0.23	-0.31	-0.29	-0.47	-0.12	-0.13
Tisiska	-0.57	-0.67	-0.68	-0.77	-0.34	-0.41
Abergele	-0.50	-0.57	-0.57	-0.58	-0.37	-0.49
Zonal level	-0.42	-0.29	-0.49	-0.36	-0.22	-0.07

4.3.5. Crop production anomalies and kiremt rainfall variability

Figure 4.15 and 4.16 shows anomalies of meher crop production (wheat & sorghum) and kiremt rainfall variability at the district level. Wheat production was below mean in the year 2007, 2009 and 2015 at Sekota, 2009, 2012-2015 at Tisiska, 2009, 2011 and 2015 at Asketema, 2008, 2009 and 2013 at Sahla, 2008, 2013 and 2015 at Abergele when kiremt rainfall was also below the mean for the same period. Above average wheat production was observed in 2010, 2012, 2013 and 2016 at Sekota, 2007, 2010, 2013 and 2016 at Amdework, 2007, 2008, 2010 and 2011 at Tisiska, 2008 and 2013 at Asketema, 2007, 2010, 2012 and 2016 at Sahla, 2007, 2010 and 2012 at Abergele. Kiremt rainfall was above average during those years. Similarly, both Sorghum production and Kiremt rainfall showed below the mean in 2007, 2009, 2011 and 2014 at Sekota, 2008, 2009, 2012, 2014 and 2015 at Amdework, 2009, 2011, 2012, 2014 and 2015 at

Asketema,2009,2012-2016 at Tisiska,2008,2009,2013-2015 at Sahla and 2088,2009,2013,2015 and 2016 at Abergele.

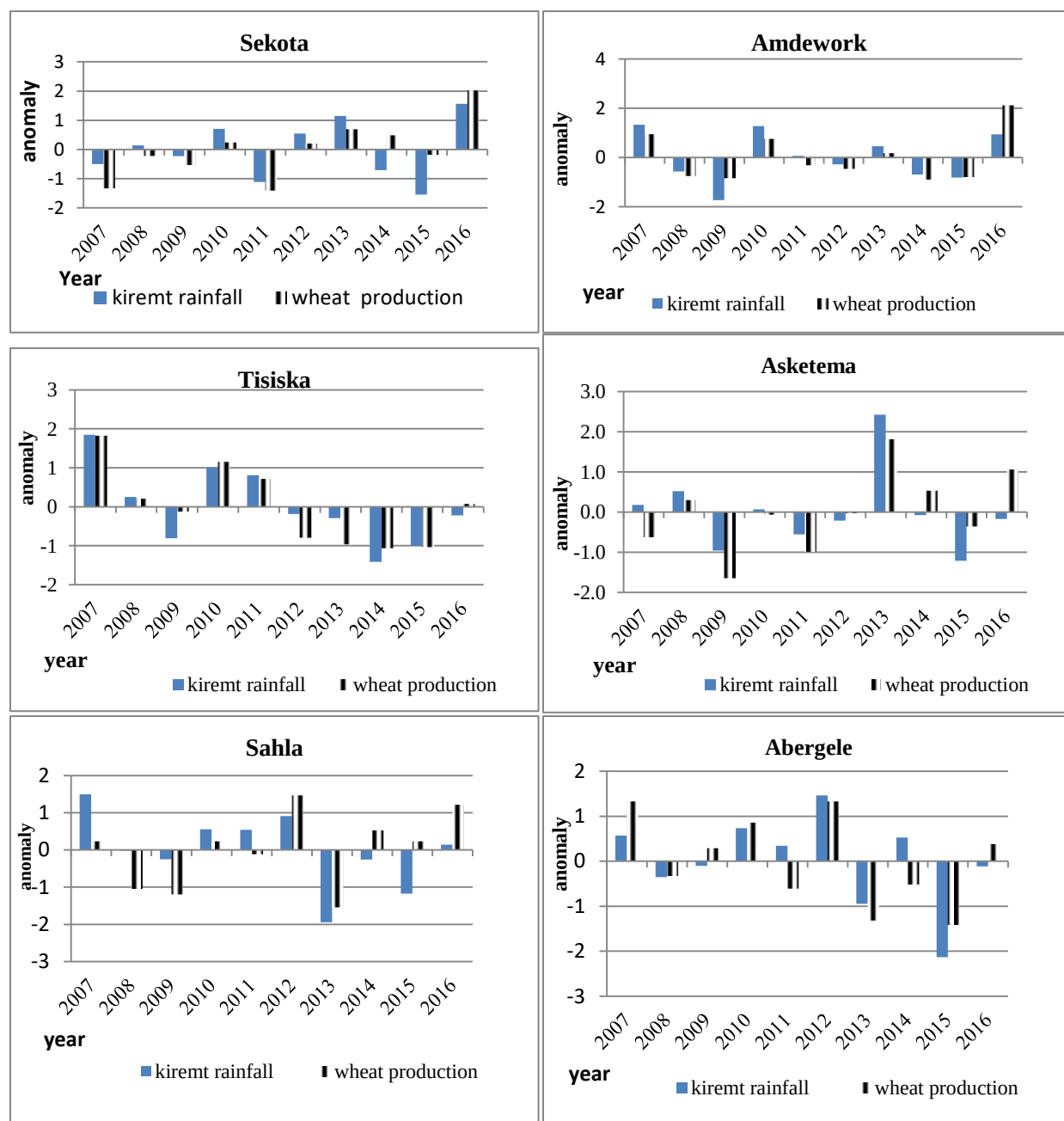


Figure 4.14Wheat production anomalies and kiremt rainfall amount

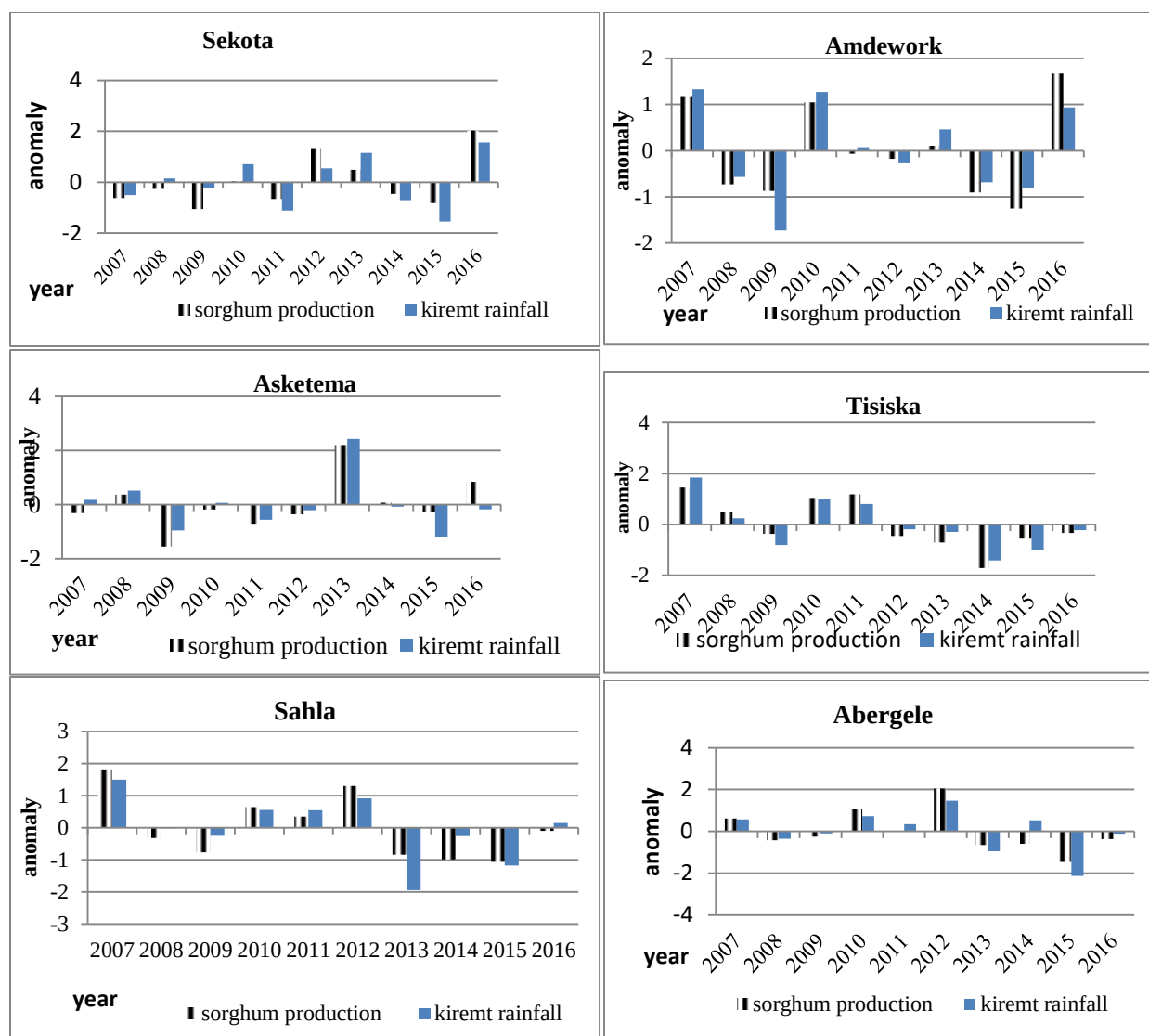


Figure 4.15. Sorghum production anomalies and kiremt rainfall amount

4.3.6. Results from the Multiple Linear Regressions Analysis

The results of multiple regressions of precipitation and temperature on crop yields are presented in (Table 4.32). Multiple regression analysis was carried out in order to determine the relationship between the climatic variables and crop yields. The analysis described the effects of the two independent variables (temperature and rainfall) jointly on the yields of the crops. The multiple regression equation (Appendix Table 5) revealed that a unit change in any of the rainfall and temperature while holding others constant, the highest variation in the yield of wheat in the area will be accounted by kiremt rainfall amount 0.015qt/ha, 0.017qt/ha at Amdework, Sahla and Tisiska areas respectively. Similarly the highest variation due to the effect of temperature on

Wheat yields 0.88qt/ha, 0.23qt/ha and 0.166qt/ha at Asketema, Sekota and Abergele district respectively. Likewise the highest variation in the yield of Sorghum in the areas will be experienced by rainfall amount 0.015qt/ha, 0.013qt/ha, 0.0263qt/ha and 0.014qt/ha at Amdework, Sahla, Sekota and Tisiska district respectively. Moreover temperature also the highest variation on Sorghum yields by 0.69qt/ha, 0.08qt/ha at Asketema and Abergele areas respectively.

In general the highest variation in yield of wheat in the area will be accounted by rainfall amount 0.014qt/ha and the least change in yield will be from temperature (-0.024qt/ha). Conversely the highest variation for sorghum yields will be accounted by temperature 0.196qt/ha and the least variation in yield will be experienced by rainfall amount (0.014qt/ha) over the last periods. These show that among the climate variables, rainfall amount is the most important variable for the variation in Wheat yield in the study area indicating that the yield of Wheat is higher when a kiremt rainfall is higher. On the other hand temperature is the most important variable for the variation in Sorghum yield in the study area implying that the yield of Sorghum is more when temperature is higher.

The precipitation and temperature variability have a significant effect on wheat yields with high coefficient of determination ranging from 0.76 at Asketema to 0.92 at Abergele district while that of sorghum also 0.8 to 0.92 at sekota and Asketema district respectively (Table 4.32).

The coefficient of determination value shows that the variation in the annual yield of Wheat and sorghum can be accounted for by the rainfall and mean temperature in the study area. The R^2 value also revealed that the yield of crops do not depend only on the climatic variables because non-climatic (agronomic) variables also affect the crop yield, but only two climatic variables (kiremt rainfall and mean temperature) were captured in this study. On the other hand the F-ratio which determines the overall significance of regression is statistically significant at 5% level of probability as F-calculated value (20-25) is greater than F-tabulated value (4.74).

In general the precipitation and temperature variability have a significant effect on wheat and sorghum yields with high coefficient of determination ranging from 0.84-0.86 respectively. Moreover about 42.6% and 56.7% of variation in wheat and sorghum production respectively can be explained by rainfall while temperature account for 41.4% and 29.3% of the variation in

production of the two crops respectively in the study area. Therefore, it is concluded that climate variability significantly affected wheat and sorghum yield. The remaining 16% and 14% of the variations in the yield of Wheat and Sorghum respectively can be attributed to other unexplained factors such as soil characteristics, farming methods, planting dates, weeds, fertilizer application, seed varieties, pest and diseases, harvesting and other climatic factors.

Table 4.32. Analysis of variance (ANOVA) of Wheat and sorghum yields with climate variables.

District	Wheat			Sorghum		
	R ²	Calculated(F)	Tabulated(F)	R ²	Calculated(F)	Tabulated(F)
Amdework	0.862	21.9	4.74	0.817	15.6	4.74
Asketema	0.763	11.2	4.74	0.917	38.7	4.74
Sahla	0.80	14.1	4.74	0.906	33.86	4.74
Sekota	0.842	18.6	4.74	0.803	14.29	4.74
Tisiska	0.839	18.2	4.74	0.903	32.61	4.74
Abergele	0.918	39.4	4.74	0.818	15.75	4.74
Average	0.84	20.57	4.74	0.86	25.14	4.74

4.3.7. Statistical indicators of regression model performance

Table (4.33) showed the observed and predicted Wheat and sorghum yield obtained from the multiple linear regression models. The comparison of simulated with observed yields allows the assessment of the model capacity to represent local crop systems. The result of coefficient of determination (R²) value in all statins revealed that a good agreement between the simulated and observed yield of both Wheat and Sorghum cops. Similarly the root mean square error RMSE) which is an overall a measure of the model performance showed a good fit between the observed and the predicted both crops. The d-statistic values close to 1 are regarded as better simulations and according to these statistical indicators the model performance was deemed satisfactory to allow continuation of simulations for both long-term (temporal) and at different locations (spatial).

Table4.33: The performance and statistical evaluation of regression equation for wheat and Sorghum yields

District	Wheat					Sorghum				
	Observed yield	Predicted yield	R ²	RMSE	D-stat	Observed Yield	Predicted yield	R ²	RMSE	D-stat
Amdework	10.3	10.28	0.86	0.99	0.99	8.9	8.78	0.82	0.37	0.99
Asketema	10.49	10.64	0.76	0.64	0.96	8.25	7.91	0.92	0.55	0.90
Sahla	7.91	7.69	0.80	0.35	0.99	9.11	9.11	0.91	0.23	0.96
Sekota	7.24	7.19	0.84	0.35	0.94	7.49	7.48	0.80	0.44	0.92
Tisiska	5.37	4.46	0.84	0.46	0.97	6.51	6.37	0.90	0.66	0.89
Abergele	7.87	7.89	0.92	0.42	0.92	7.4	7.5	0.82	0.75	0.93
Zonal level	8.19	8.21	0.97	0.112	0.96	7.93	7.93	0.99	0.56	0.93

4.4. The future climate and possible implications for wheat and sorghum crops

Appendix Table 18 shows that the percentage change of the simulated wheat and sorghum yields from the base line from the 20 GCMs ensemble outputs under Rcp4.5&Rcp8.5 scenarios during the period 2050s and 2080s for the study area. Projected increases in temperatures, changes in precipitation patterns, changes in extreme weather events, and reductions in water availability may all result in reduced agricultural productivity. The table revealed that the yield of wheat and sorghum under the projected future climate would be varying with emission scenarios and stations location.

The simulated wheat yields for the future climate scenarios expected to be lower than the base line at Amdework, Sahla and Sekota areas for the period 2050s and 2080s under the two emission scenarios except at Sekota the yield of wheat expected to be increment by 2080s under Rcp8.5. By the contrary yield of wheat would be increase at Asketema, Tisiska and Abergele areas by 2050s and 2080s for all scenarios except at Abergele under Rcp8.5 by 2080s showing decline. In addition the yield of sorghum expected to be decline at Amdework and Sekota areas by 2050s and 2080s under the two emission scenarios. Conversely the projected yield of sorghum will be increase at Sahla, Tisiska and Asketema areas for all scenarios by 2050s and 2080s except at Asketema under Rcp4.5 by 2050s expected to be decline. On the other hand the probable yield of sorghum also expect to increase and decrease under Rcp4.5 and Rcp8.5 respectively by 2050s

and 2080s. The global average temperature risk is high to very high with global mean temperature increase of 1.5 °C to 5.4 °C at the end of the century from the preindustrial level with a widespread impact on global and regional food security and normal human activities, including growing food (IPCC, 2014).

Holding all other factors constant 2-2.6°C rise in temperature and 1.7-2.7% decrease in rainfall will result in 4.9-6.1% reduce in Wheat by 2050s and 2080s while that of Sorghum production reduces 1.3% by 2050s under Rcp4.5 emission scenarios in Waghemra Zone. Projected mean yield change showed a consistent decline for Wheat yields across emission scenarios largely as a result of temperature increase. Wheat is a cool season crop and increasing temperature shortens its growth period by accelerating phenological developments, resulting in reduced yield (Asseng *et al.*, 2011). Studies suggested that a 1°C increase in temperature above optimum (15-20°C) reduces wheat yield by 10% (Brown, 2009) and studies confirmed that wheat is negatively affected by future projected climate compared to other crops in East Africa (Liu et al. 2008). By the contrary increase in sorghum yields shown by almost under both RCPs, may be attributed to increase in temperatures and the slight changes in projected rainfall which appear to create conducive conditions for sorghum growth, being more tolerant to heat and water stress.

It has been shown that Sorghum yields will consistently increase over different time periods with up to 9.1% increase towards the end of the century. On the other hand, overall Wheat yields, by contrast have been projected to decline. A study by Adhikari et al. (2015) reported that wheat is one of the most vulnerable crops to climate change and two-thirds of production loss is expected in eastern Africa by the end of the 21st century.

These findings are consistent with those of other studies that have shown similar negative effects on Wheat, under current varieties and crop management practices, without adaptation strategies. Basic agronomic adaptation options such as fertilizer applications, appropriate planting density and planting dates appear to be ideal for future climate uncertainties. This has a bearing on agricultural plans and policies which may need to be reoriented for enhanced crop productivity.

5. SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 .Summary and Conclusions

Information on seasonal Kiremt and seasonal Belg rainfall amount is important in the rain fed agriculture of Ethiopia since more than 85% of the population is dependent on agriculture particularly on rain fed farming practices (Tuffa A., 2012).But climate variations influences agricultural production and hence it affects crop productivity and land use pattern. This study investigated the effect of current and future climate variability on major crop production (wheat and sorghum) in Waghembra zone, Ethiopia.

The annual and seasonal distribution of rainfall also varied among stations. Stations located at the lowland area recorded lower mean annual rainfall than station at the highland and midland agro-ecological zones. The analysis on long term rainfall data for the study area showed large inter-annual and seasonal variation in the amount and distribution of rainfall. The observed trends showed a decreasing trend in belg rainfall while increasing rainfall in both annual and kiremt total rainfall, but the trend was non-significant in the time series.

The areal annual and kiremt rainfall have increased with a rate of 3.7mm and 5.4 mm per year respectively while belg rainfall has decreased with a rate of 3mm per decade. However, the detected trends were statistically non-significant. Over the last periods trends of rainfall events such as onset date, cessation date and length of the growing period were changed non-significantly with a rate of 1, 2 and 1days /decade respectively in the study area.

During the last 31 years the annual frequency of warm days and night has increased by 1 and 0.4days/decade respectively. But the number of cold days and nights has decreased by 1 day per decade. The study area is characterized with mean annual maximum temperature varies from 24.4°C to 30.5°C with mean of 26.3°C. The mean annual minimum temperature also varies from 10.4°C to 16.1°C with a mean of 12.3°C. In addition the mean annual temperature varies from 17.7°C to 23 °C with a mean of 23°C over the last 3 periods.

The coefficient of variation is higher for minimum temperature than maximum and average temperature in Waghembra Zone over the last 3 decades.

Both minimum and maximum temperature showed significantly increasing trends during annual and seasonal time scale at all locations for the past 3 decades. The result of the correlation analysis shows that rainfall amount had strong positive correlation $r=0.87$ and $r=0.92$ for wheat and sorghum yields respectively. Likewise the result revealed that correlation between mean temperature and crop yields (wheat & sorghum) weak negative correlation with $r=-0.42$ and $r=-0.29$ for wheat and sorghum yields respectively. It was also observed that the rainfall and temperature jointly contributed 84% and 86% in explaining the variations in the yield of wheat and sorghum per hectare respectively in the Waghemra Zone. The result of the regression model also reveal that the kiremt rainfall amount and mean temperatures have the strongest influence on Wheat and Sorghum yields per hectare respectively in the study area.

The variability of seasonal rainfall causes fluctuations in production of major crops. Due to high correlations between crop production and seasonal rainfall, small changes in amount and distribution of seasonal rainfall causes significant negative impacts on crop production that varies from reduced yield to the total loss of the crop.

As result both wheat and sorghum production exhibits the largest year to year variations in the study area. This high inter-annual variability is caused by climate variability where in the climate components of temperature and precipitations often play the biggest role.

The annul total rainfall amount is projected to be decreased by 2.8% by 2050s and 1.6% by 2080s for Rcp4.5 emission scenario. Conversely the Rcp8.5 scenario showed increment of annual rainfall by 1.6-4.9% by 2050s and 2080s respectively in the study area. On average the projected kiremt rainfall will be decreased by 2.7% by 2050s and 1.7 % by 2080s under Rcp4.5 while that of Rcp8.5 scenario showed increment by 0.79-2.8% by 2050s and 2080s respectively. On the other hand the projected belg rainfall will be increased by 1.8 - 2.6% by 2050s under Rcp8.5 and 4.5 emission scenarios respectively while for the end-century (2080s) the probable belg rainfall expected to be decreased by 2.9% and increment by 4.8% under Rcp4.5 and 8.5 scenarios respectively.

The average annual minimum temperature is projected to be increased by 1.9-2.5 °C for the period 2050s under Rcp4.5 and Rcp8.5 emission scenarios respectively and 2.4-4.3 °C for the period 2080s under Rcp4.5 and Rcp8.5 respectively.

Likewise the maximum temperature projected to be increased by 1.8-2.4 °C and 2.3-3.7 °C for the mid and end-century respectively under Rcp4.5 and Rcp8.5 over the study area. The mean annual temperature is projected to be increased within the range of 1.9-2.8 °C and 2.4-4.1 °C by 2050s and 2080s respectively for Rcp4.5 and Rcp8.5 emission scenarios in Waghemra Zone. At seasonal level the mean temperature also expected to be increased within the range of 2-2.7 °C and 2.6-4.4 °C during kiremt season for the period 2050s and 2080s respectively for medium and high emission scenarios while for belg season the average temperature will be increased by 1.7-2.5 °C and 2.3-4.1 °C over the next medium and end-century based on emission scenarios.

The rate of warming is expected to be higher towards the end of the century at all studied stations, particularly under the highest emission scenario. Generally past and future trends in inter-annual and inter-seasonal rainfall variability, declining rainfall amount, variability in the length of the growing seasons and in-season dry spells together with increasing temperature indicate an increasing risk for rain-fed crop production in the Waghemra Zone. The increasing temperature will increase the rate of evapotranspiration and crop water requirements, adding to the currently frequent water stress of crops. As result the impact of future climate on sorghum and wheat production revealed that yield response of both crops vary with emission scenarios and locations.

Analysis of climate change scenarios showed that wheat yield will decrease on average by 2.4-6.1% and 1.2-4.9% by 2050s and 2080s respectively under Rcp4.5 and 8.5 scenarios relative to a baseline yield due to an increase in temperature and a decrease in growing season rainfall.

The projected mean yield change showed more decline at mid-term (2050s) for both emission scenarios. Similarly the projected yields of sorghum have shown increment by 2.6-9.1% by 2050s and 2080s respectively under Rcp8.5 emission scenario. On the other hand the simulated yield of sorghum expected to decline by 1.3 % by 2050s and increase by 1.3% by 2080s under Rcp4.5 in the study area.

It has been shown that Sorghum yields will consistently increase over different time periods with up to 9.1% increase towards the end of the century. On the other hand, overall Wheat yields, by contrast have been projected to decline.

5.2 Recommendations

Evidently, from the study findings climate variability has an adverse effect on crop production in Waghemra Zone. Thus, there is need for a wide-ranging policy that will elevate the potential of rain fed agriculture in the midst of the risks posed by climate variability.

The significant response of wheat and sorghum output to climate variability points to a possible decline in crop production in the future, in absence of adaptation and mitigation mechanisms.

Furthermore, the study finds that, variability in temperature and timing of rainfall affects crop yield. Thus, provision of timely information on expected changes on these variables is critical in improving awareness and for rapid consideration for adaptation.

To achieve this rain water harvesting is recommendable to supplement water supply for small scale and large-scale irrigation. This is achievable at the household level, through water conservation coupled with investments in more efficient storage infrastructure. In addition, local communities, nongovernmental organizations and the county governments should facilitate construction of water collection dams for irrigation purposes managed at the community level. There is also the need to equip farmers with requisite technical support to ensure better management of irrigation schemes to avoid water loss or excess watering of crops especially in rainy periods. Improving agricultural extension services and introducing new agricultural technologies and communicating projected climate change impacts and possible management strategies effectively among farmers and decision makers that can help to increase major crop productivity. Generally, expanding irrigation and water management practices, strengthening awareness of farmers and early warning responses, shift to early maturing and drought resistant crops, diversifying livelihood opportunities, ensuring access to rural finance, promoting perennial trees like fruits in the highlands and fast maturing cash crops in the lowlands, intensive use of inputs and better land management practices are some of the strategies

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7. APPENDICES

Table 1.Descriptive statistics of the onset, cessation and length of the kiremt rainy season during1986-2016

Station	Rainfall Event	Min	Max	Mean	SD	CV	Q1 (25%)	Q2 (50%)	Q3 (75%)
Amdework	SOS	160	221	186	13	7	179	186	195
	EOS	245	285	261	10.9	4.2	249	261	265
	LGP	24	110	74	17.4	23.6	61	74	85
Asketema	SOS	166	216	187	11.3	6	180	187	196
	EOS	245	283	255	8.4	3.3	248	255	258
	LGP	29	91	70	14.8	22.1	56	70	74
Sahla	SOS	174	218	190	8.9	4.6	186	190	196
	EOS	245	265	250	6.8	2.7	245	250	257
	LGP	29	83	66	13.7	21.6	52	66	74
Sekota	SOS	153	235	190	18	9.6	181	190	199
	EOS	245	264	248	6.1	2.4	245	248	256
	LGP	17	92	62	17.1	27.4	54	62	74
Tisiska	SOS	160	236	193	14.1	7.3	187	193	199
	EOS	245	266	248	6.6	2.6	245	248	254
	LGP	13	85	60	16.8	29.5	47	60	72
Abergele	SOS	163	215	190	11.49	6.1	181	190	194
	EOS	245	258	246	4.37	1.8	245	246	251
	LGP	31	82	58	12.35	20.8	53	58	71
Zonal level	SOS	173.8	210.2	190.1	7.05	3.7	186.7	188.7	192.7
	EOS	245	261.7	252.5	5.5	2.2	248.5	251.5	258.5
	LGP	45	77.7	63.8	8.3	13	57.8	64	71.3

SOS=indicates onset date of the season, EOS=cessation date of the season, LGP=length of the season, Min=minimum value, max=maximum value, sd indicates standard deviation, cv=coefficient of variation, Q1=first quartile, Q2=second quartile, Q3=third quartile

Table2. Descriptive statistics of number of rainy and dry days in kiremt season at waghemra zone

Station	Rainfall Indices	Min	Max	Mean	SD	CV	Q1 (25%)	Q2 (50%)	Q3 (75%)
Amdework	NRD	30	84	61.9	10.4	16.8	56	63	69
	NDD	38	92	60.1	10.4	17.4	53	59	60
Asketema	NRD	23	84	53.3	12.9	24.2	45	56	62
	NDD	38	99	68.6	12.9	18.9	60	66	77
Sahla	NRD	40	74	58.8	9.3	15.8	54	60	66
	NDD	48	82	63.1	9.2	14.6	56	62	68
Sekota	NRD	20	69	42.2	9.9	23.5	37	44	49
	NDD	69	102	80.8	8.6	10.7	73	80	85
Tisiska	NRD	26	71	49.4	11.2	22.7	42	50	60
	NDD	51	98	73.6	12.2	16.6	62	72	82
Abergele	NRD	37	72	51	9.7	18.6	43	51	57
	NDD	50	85	71	10.7	15.5	60	71	77
Areal mean	NRD	31	63	52.9	7.5	14.2	50	53	59
	NDD	49	93	69.5	10.7	15.6	60.7	68.3	74.8

NRD is number of rainy day, NDD is number of dry day, min=maximum, min=minimum, Q3 third quartile, SD=standard deviation, CV is coefficient of variation, Q1 first quartile, Q2 is second quartil

Table3.Descriptive statistics of annual, mean, maximum and minimum temperature in the study area for the period 1986-2016

Stations	Minimum temperature					Maximum temperature					Average temperature				
	Min	Max	mean	Sd	Cv	Min	Max	mean	Sd	Cv	Min	max	Mean	Sd	Cv
Amdework	8.5	11.8	10.1	0.79	7.8	21.2	26.5	23	0.97	4.2	15.2	18.2	16.6	0.79	4.8
Asketema	9.13	13.57	10.8	0.8	7.4	22.7	28.3	24.2	1.07	4.4	16.4	20.9	17.5	0.87	4.9
Sahla	11.9	19.1	13.7	1.34	9.8	26.7	32.9	28.6	1.3	4.6	19.46	25.9	21.1	1.25	5.9
Sekota	10.2	13.6	12.3	0.76	6.1	24.8	27.7	26.3	0.78	2.9	17.85	20.3	19.3	0.64	3.3
Tisiska	11.2	18.7	13.6	2.13	15.6	26.1	34.2	28.4	2.44	8.6	19.1	26.5	21.0	2.22	10.6
Abergele	11.5	20	13.4	1.67	12.5	24.7	33.4	27.5	1.68	6.1	18.1	26.4	20.5	1.63	8
Areal mean	10.7	15.6	12.3	1.03	8.4	24.6	30.5	26.3	1.2	4.6	17.9	22.8	19.3	1.1	5.7

Table4. Descriptive statistics of kiremt mean maximum and minimum temperature at six stations

Stations	Minimum temperature					Maximum temperature					Average temperature				
	Min	Max	mean	Sd	Cv	Min	Max	Mean	Sd	Cv	Min	Max	Mean	Sd	Cv
Amdework	8.1	12.3	10.4	0.95	9.2	19.1	25.7	20.7	1.2	5.8	14.1	18.7	15.6	0.92	5.9
Asketema	9.3	14.5	11.5	0.86	7.5	19.1	25.7	20.7	1.2	5.8	15.8	21.3	17.2	1.02	6.0
Sahla	12.2	19.7	14.7	1.4	9.5	24.7	33	26.8	1.8	6.7	19	26.1	20.8	1.5	7.2
Sekota	10.1	14.9	13.1	1.2	9.3	23.8	29.2	25.8	1.2	4.6	17.1	21.9	19.5	1.1	5.5
Tisiska	11.3	19.3	14.5	2.1	14.3	22.7	33.8	26.4	3.2	12	17.7	26.1	20.4	2.5	12.3
Abergele	11.9	19.9	14.5	1.59	11	19.8	33.9	25.8	2.27	8.8	15.8	26.6	20.1	1.85	9.2
Average	11.1	15.9	13.1	0.96	7.3	23.1	30.2	24.7	1.5	5.9	17.8	22.5	18.9	1.1	5.7

Table (5). The multiple regression equations

District	multiple regressions equation for wheat	multiple regressions equation for sorghum
Amdework	$Y=0.015*\text{rain}-0.355*\text{temp}+4.419$	$Y=0.015*\text{rain}-0.251*\text{temp}+1.201$
Asketema	$Y=0.008*\text{rain}+0.883*\text{temp}-11.261$	$Y=0.006*\text{rain}+0.693*\text{temp}-9.063$
Sahla	$Y=0.017*\text{rain}-0.252*\text{temp}+3.944$	$Y=0.0131*\text{rain}-0.0432*\text{temp}+2.918$
Sekota	$Y=0.0249*\text{rain}+0.2259*\text{temp}-8.013$	$Y=0.0263*\text{rain}-0.1908*\text{temp}-0.3816$
Tisiska	$Y=0.017*\text{rain}-0.065*\text{temp}-0.528$	$Y=0.014*\text{rain}-0.149*\text{temp}+4.452$
Abergele	$Y=0.0287*\text{rain}+0.166*\text{temp}-9.919$	$Y=0.023*\text{rain}+0.081*\text{temp}-5.359$
Zonal level	$Y=0.014*\text{rain}-0.024*\text{temp}+0.787$	$Y=0.014*\text{rain}+0.196*\text{temp}-3.88$

Analysis of variance at the zonal level

Wheat	Source	Df	SS	MS	F	Sig	Sorghum	Source	Df	SS	MS	F	Sig
	Model	2	21.5	10.7	10.6	0.008		Model	2	18.4	9.2	21.9	0.001
	Error	7	7.1	1.01				Error	7	2.9	0.42		
	Total	9	28.6					Total	9	21.3			

Variables in the multiple regression equations

Wheat	Parameter	Estimate	SE	T	Sig	Sorghum	Parameter	Estimate	SE	T	Sig
	Const	0.787	6.49	0.12	0.91		Const	-3.88	4.17	-0.92	0.38
	Temp	-0.024	0.269	-0.09	0.93		Temp	0.196	0.17	1.13	0.29
	Rain	0.014	0.003	4.05	0.005		Rain	0.014	0.002	6.32	0.004

Df=degree of freedom, SS=sum squares, MS=mean squares, SE=standard error, sig=significance at 95% confidence level, Const=constant, Temp=temperature

Table 6.Descriptive statistics of annual number of warm day and night, number of cool day and night at six representative stations during the period 1986-2016

Stations	Temperature events	Min	Max	Mean	SD	CV
Amdework	warm day	24.2	30.3	26.5	1.1	4.2
	warm night	10.4	14.5	12.2	0.99	8
	Cool day	16.9	24.3	18.6	1.3	6.7
	Cool night	6.1	9.3	8	1.01	13.1
Asketema	warm day	24.9	31.5	27.2	1.3	4.7
	Warm night	11.4	15.7	12.8	0.79	6.2
	Cool day	18.3	25.5	20.6	1.5	7
	Cool night	6.5	11.6	8	1.1	13.6
Sahla	warm day	29.8	35.6	31.7	1.2	3.8
	warm night	14.5	21	15.7	1.3	8.1
	Cool day	18.3	29.6	24.9	2.8	11.3
	Cool night	8.6	16.9	10.8	1.7	16.6
Sekota	warm night	25.6	31	29.4	1.1	3.6
	Cool day	13	16.6	15.2	0.85	5.6
	Cool night	9	24.4	23.1	4.3	20.2
	warm day	4	11.2	9	1.7	18.8
Tisiska	warm night	29	37.8	31	2.6	8.1
	Cool day	12.6	22.5	15.3	2.1	13.4
	Cool night	18.3	30.2	22.9	2.9	12.5
	warm day	7	16	9.8	2.4	23.3
Abergele	warm night	28.6	36.3	31	1.4	4.5
	Cool day	14.3	23.8	15.6	1.8	11.4
	Cool night	18.3	30.6	23.7	2.7	11.5
	Warm day	8.5	16.5	9.4	1.9	19.5

Table 7. Descriptive statistics of the projected kiremt rain fall in mid and end-century from the mean of 20 GCMs under Rcp4.5 and Rcp8.5 emission scenario in the study area.

Stations	RCP4.5						RCP8.5				
	Period	Min	Max	Mean	Sd	Cv	Min	Max	Mean	Sd	Cv
Amdework	2050s	262.9	1646.6	738.4	283.9	38.5	277.7	1712.1	773.4	296.1	38.3
	2080s	264.9	1666.4	744	286.8	38.5	292.4	1835.7	795.8	311.3	39.1
Asketema	2050s	185.1	1563.4	596.1	283.8	47.6	202.3	1619.7	619.5	294.5	47.5
	2080s	193.3	1606	627.2	293.6	46.8	212.8	1664.2	642.1	302.7	47.1
Sahla	2050s	289.9	767.2	513.9	111.5	21.7	299.1	798.9	536.6	116	21.6
	2080s	289.2	773	517.2	112.2	21.7	295.7	811.5	537.3	117.4	21.9
Sekota	2050s	132.7	605.3	401.9	131.8	32.8	137.1	632.2	412.8	131.7	31.9
	2080s	142.7	625.6	412.3	130.5	31.6	144	655.6	420.9	134.6	32
Tisiska	2050s	219.7	725.3	459.3	141.2	30.7	233.9	762.5	485.9	148.8	30.6
	2080s	222.7	732.7	465.9	143.6	30.8	237.5	785.9	491.3	151.3	30.8
Abergele	2050s	265.8	873.7	460.8	129.6	28.1	278.1	901.8	479.9	134	27.9
	2080s	268.3	861.9	459.9	127.7	27.8	283.4	920.7	487.5	136.6	28
Areal mean	2050s	226	1030.3	528.4	180.3	33.2	238	1071.2	551.4	186.8	32.9
	2080s	230.2	1044.3	537.8	182.4	32.9	244.3	1112.3	562.5	192.3	33.2

Table8. Descriptive statistics of the projected annual rain fall in mid and end-century from the mean of 20 GCMs under Rcp4.5 and Rcp8.5 emission scenario in the study area.

Stations	RCP4.5						RCP8.5				
	Period	Min	Max	Mean	Sd	Cv	Min	Max	Mean	Sd	Cv
Amdework	2050s	349.5	1798.2	870.1	287.9	33.1	366.3	1859	903.3	299.7	33.2
	2080s	357.5	1807.7	875.4	290.3	33.2	385.7	1997.2	936.5	316.4	33.8
Asketema	2050s	363.8	1571	713.2	261.1	36.6	367.3	1628.7	741.7	270.8	36.5
	2080s	376.9	1613.8	728.7	270.7	37.2	384.8	1674.9	775.3	274.7	35.4
Sahla	2050s	304.5	789.3	550.7	110.1	20	315.1	822.3	574.7	114.7	20
	2080s	303.9	795.1	555.9	111.4	20	313.5	835.3	577.9	115.9	19.9
Sekota	2050s	276.3	804.8	574.8	146.3	25.5	281.5	821.3	592.8	150.9	25.5
	2080s	295	832.3	590.9	148.5	25.1	301.1	876.3	626.6	162.2	25.9
Tisiska	2050s	254.8	738.6	514	139	27.2	269.2	776.4	542.8	146.9	27.1
	2080s	257.6	745.9	520.5	140.3	27	276.1	800.1	552.5	149.2	27
Abergele	2050s	311	898.7	508.8	123.5	24.3	323.5	928.7	528.5	127	24
	2080s	311	888	507.1	120.7	23.8	322.8	950.6	540.7	127.8	23.6
Areal mean	2050s	309.9	1100.1	621.9	177.9	27.8	320.5	1139.4	647.3	185	27.7
	2080s	316.9	1113.8	629.8	180.3	27.7	330.7	1189.1	668.3	191	27.6

Table 9.Descriptive statistics of future onset date, cessation date and length of growing period from the ensemble mean of 20 GCMs under Rcp4.5 and Rcp8.5 emission scenario at six stations in the mid-century (2050s).

Stations	RCP4.5						RCP8.5				
	Rainfall event	Min	Max	Mean	SD	CV	Min	Max	Mean	SD	CV
Amdework	SOS	154	209	185	11.2	6.1	154	209	182	11.4	6.2
	EOS	245	285	258	10.8	4.2	245	286	260	10.4	4
	LGP	49	103	74	16.2	22	51	103	77	14.6	19
Asketema	SOS	166	215	187	11.3	6	166	215	187	12.1	6.5
	EOS	245	266	251	6.6	2.6	245	266	252	6.7	2.7
	LGP	30	92	63	14	22.2	30	92	65	14	21.6
Sahla	SOS	173	217	191.2	9.2	4.8	173	217	190.5	9.9	5.2
	EOS	245	266	250	6.5	2.6	245	266	251	6.9	2.8
	LGP	28	87	58	11.8	20	28	89	60	12.8	21.1
Sekota	SOS	170	236	190.8	13.7	7.2	169	236	191.2	18.2	9.5
	EOS	245	259	247	4.3	1.7	245	261	249	4.9	2
	LGP	18	75	56	13..6	24	22	76	58	18.7	32.4
Tisiska	SOS	158	220	191.5	11.9	6.2	158	220	190.8	11.9	6.2
	EOS	245	267	249.7	6.7	2.7	245	267	251	7.3	2.9
	LGP	24	91	58	14.7	25.2	29	92	60.4	14.8	24.5
Abergele	SOS	158	237	191	15.4	8	158	237	191	16.3	8.6
	EOS	245	289	263	11.4	4.3	245	290	264	11.6	4.4
	LGP	23	105	72	20.4	28.3	25	106	74	19.8	26.7

Table 10.Descriptive statistics of future onset date, cessation date and length of growing period from the ensemble mean of 20 GCMs under Rcp4.5 and Rcp8.5 emission scenario at six stations in the end-century (2080s)

Stations	RCP4.5						RCP8.5				
	Rainfall event	Min	Max	mean	SD	CV	Min	Max	mean	SD	CV
Amdework	SOS	154	209	185	11.2	6.1	166	209	185	9.6	5.2
	EOS	245	285	259	10.6	4.1	245	287	261	10.5	4
	LGP	49	103	74	15.8	21.3	49	103	75	14.5	19.2
Asketema	SOS	166	215	188	11.3	6	166	215	189	11.6	6.2
	EOS	245	267	252	6.9	2.7	245	267	253	7	2.8
	LGP	30	92	64	14.2	22	30	92	64	14	21.8
Sahla	SOS	173	217	192	9.2	4.8	173	207	190	7.5	3.9
	EOS	245	266	250	6.6	2.6	245	266	252	7.3	2.9
	LGP	28	87	59	12	20.3	38	247	75	47.7	64
Sekota	SOS	170	251	193	17.4	9.1	169	251	193	17	8.8
	EOS	245	260	248	4.7	1.9	245	263	250	5.7	2.3
	LGP	18	75	55	17.8	32.1	18	77	56	17.8	31.6
Tisiska	SOS	158	220	191	11.9	6.2	158	220	192	11.1	5.8
	EOS	245	267	250	6.9	2.8	245	268	252	7.7	3.1
	LGP	27	91	59	14.8	25.1	30	93	60	14.5	24
Abergele	SOS	158	257	193	19.1	9.9	158	214	191	12.4	6.5
	EOS	245	290	264	11.7	4.4	245	290	266	11.5	4.3
	LGP	11	106	71	24.5	34.5	39	105	74	17.5	23.5

Table 11.Descriptive statistics of the projected mean annual maximum temperature at selected stations for the period 2050s and 2080s under Rcp4.5 and Rcp8.5

Stations	RCP4.5						RCP8.5				
	Period	Min	Max	Mean	Sd	Cv	Min	Max	Mean	Sd	Cv
Amdework	2050s	22.9	28.3	24.9	0.94	3.8	23.6	28.9	25.5	0.95	3.7
	2080s	23.6	29	25.5	0.94	3.7	25.3	30.6	27.2	0.93	3.4
Asketema	2050s	24.6	30.1	26.1	1.1	4.1	25.1	30.7	26.5	1.4	5.4
	2080s	25.1	30.7	26.7	1.1	4	26.8	32.4	28.3	0.92	3.3
Sahla	2050s	28.7	34.6	30.4	1.24	4.1	23.8	30.3	25.5	1.26	5
	2080s	29.3	35.2	31	1.27	4.1	29.3	35.3	31.1	1.25	4
Sekota	2050s	25.6	29.9	27.9	1.0	3.6	26.6	30.5	28.5	0.95	3.3
	2080s	25.3	30.5	28.4	1.1	4	25.7	32.2	29.4	1.48	4.9
Tisiska	2050s	27.9	36	30.1	2.32	7.7	26.5	36.6	30.7	2.44	7.9
	2080s	27.3	36.5	30.6	2.38	7.8	27.3	38.3	32.3	2.51	7.8
Abergele	2050s	27.8	35.4	29.6	1.5	5.2	28.3	35.9	30.2	1.5	5.1
	2080s	28.3	35.9	30.1	1.6	5.2	30	37.6	31.8	1.6	4.9

Table 12.Descriptive statistics of the projected mean annual minimum temperature at selected stations for the period 2050s and 2080s under Rcp4.5 and Rcp8.5

Stations	RCP4.5						RCP8.5				
	Period	Min	Max	Mean	Sd	Cv	Min	Max	Mean	Sd	Cv
Amdework	2050s	10.5	14.5	12.1	0.87	7.2	11.2	14.5	12.7	0.78	6.1
	2080s	11.1	14.3	12.6	0.74	5.9	13.1	16.4	14.7	0.77	5.3
Asketema	2050s	11	15.5	12.7	8.26	6.5	11.8	16.3	13.4	0.83	6.2
	2080s	11.6	16.1	13.2	0.84	6.4	13.7	18.2	15.4	0.82	5.4
Sahla	2050s	13.7	20.9	15.5	1.36	8.7	14.7	18.9	16.1	0.92	5.7
	2080s	14.4	21.5	16.1	1.35	8.4	15.1	19	17.8	0.88	5
Sekota	2050s	12.2	18.9	14.4	1.22	8.5	12.6	16.9	14.9	0.89	6
	2080s	12.5	16.8	14.6	0.95	6.5	12.6	18.9	16.3	1.79	11
Tisiska	2050s	12.5	20.6	15.2	1.91	12.6	12.9	21.4	15.8	1.95	12.3
	2080s	12.7	21.2	15.7	1.92	12.2	13.1	23.3	17.6	2.19	12.5
Abergele	2050s	13.5	21.8	15.3	1.7	10.9	14.5	22.6	16.1	1.6	10.3
	2080s	13.8	22.4	15.9	1.7	10.6	16.1	24.5	17.9	1.7	9.3

Figure (1). Trends of observed annual rainfall for the selected stations

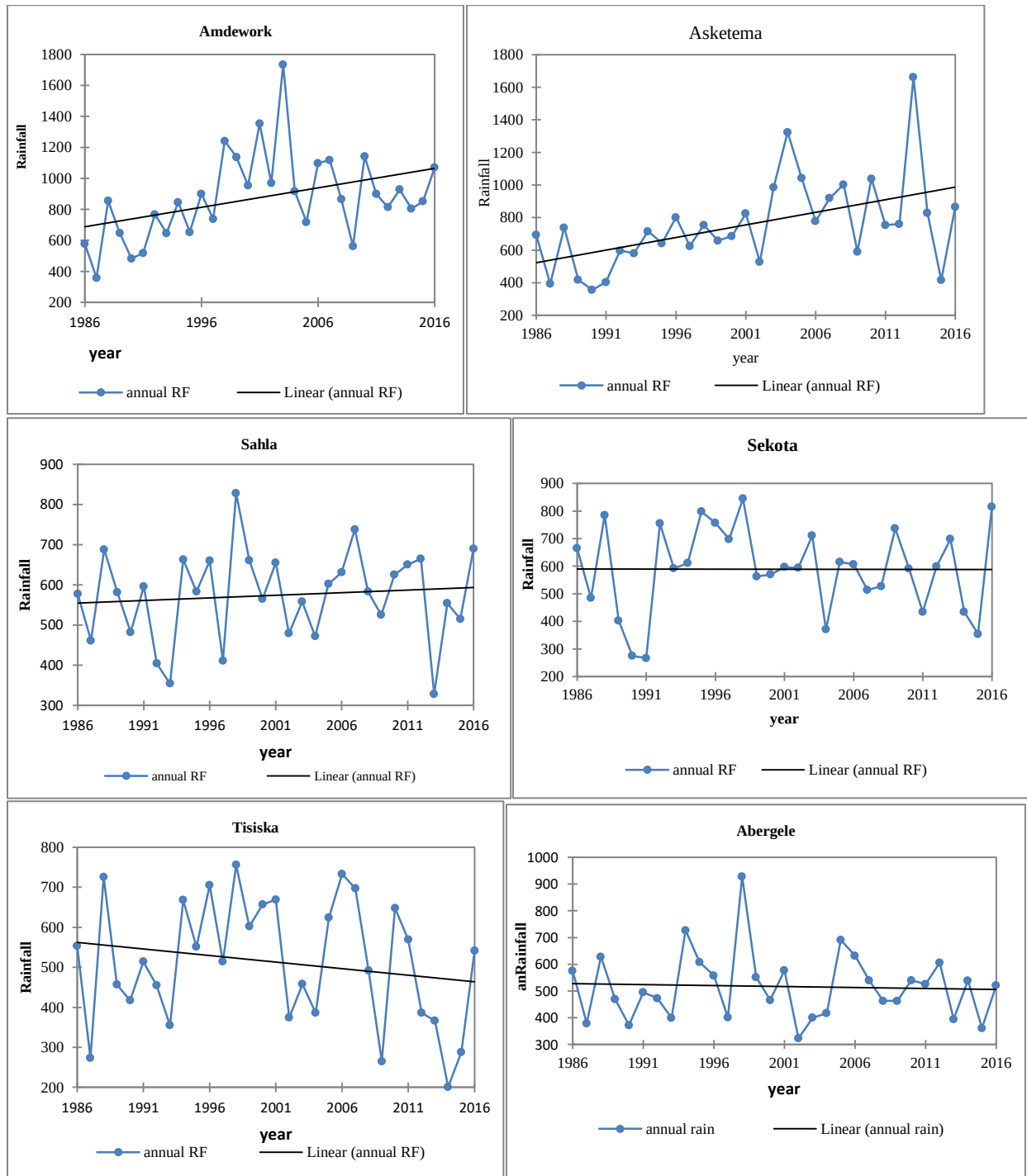


Figure (2). Trends of annual maximum and minimum temperature

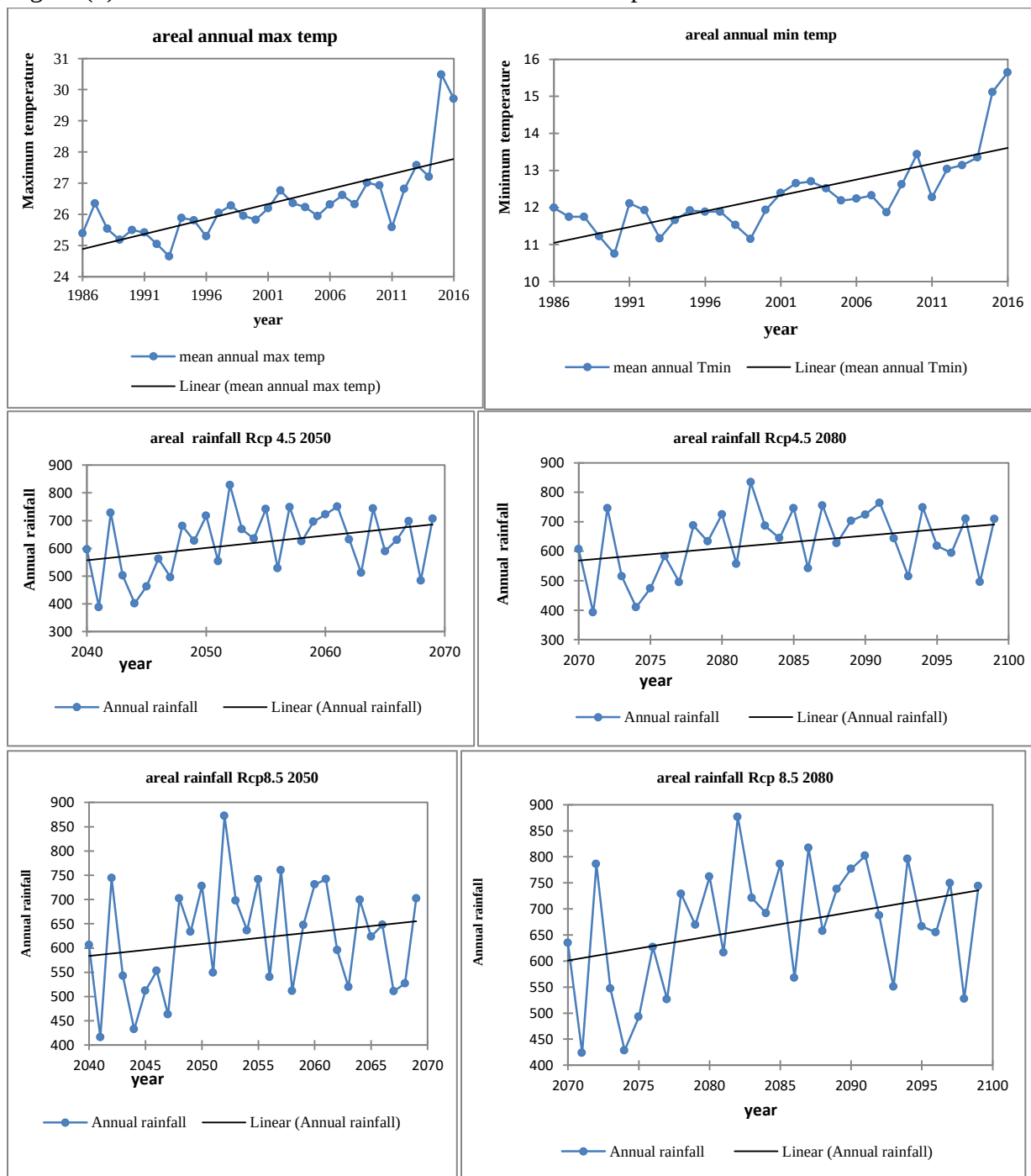


Figure (3).Trends of projected areal average annual temperature (2050s&2080s)

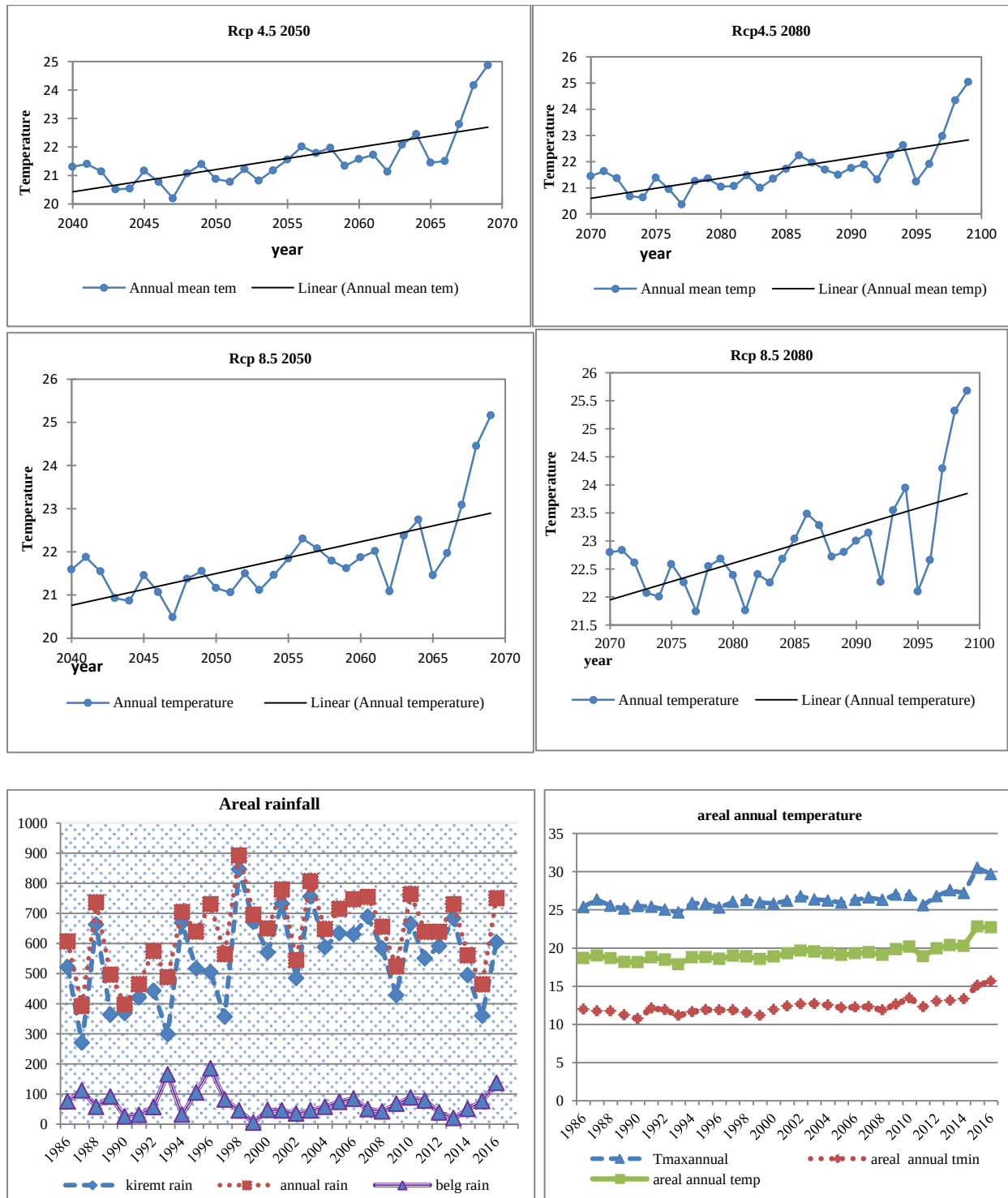


Table (13).Total annual rainfall for the selected meteorological stations

Year	Amdework	Asketema	Sahla	Sekota	Tisiska	Abergele
1986	577	694	577	665	553	575
1987	358	394	461	485	273	379
1988	855	738	688	785	726	628
1989	647	419	581	403	457	470
1990	482	356	482	275	417	372
1991	517	404	596	267	514	495
1992	767	597	404	755	455	473
1993	646	581	354	592	355	399
1994	846	716	663	611	668	727
1995	653	643	583	798	551	608
1996	900	802	660	757	705	558
1997	738	625	411	698	514	401
1998	1241.7	755	828	845	756	928
1999	1137.2	659	661	562.8	602	552
2000	953.6	686	565	569.8	657	466
2001	1353.9	825	655	596.8	669	577
2002	969.5	528	479	593.9	374	323
2003	1734.4	985.9	558	710.7	458	400
2004	916.6	1323.7	472	370.7	386	417
2005	718	1042.7	602	614.9	624	691
2006	1096.9	778.3	631	606.8	733	632
2007	1118.8	918.9	738	513.5	697	540
2008	865.1	1002.5	583	527.6	492	463
2009	561.3	590.6	525	736.8	264.7	463
2010	1142.5	1038.3	625	591.6	647.9	540
2011	899	753.5	650	433.9	569	526
2012	813.9	760.9	665	598.8	386	606
2013	928.4	1662	328	698.6	366.6	395
2014	803.6	828.8	554	434.7	200.7	539
2015	851.7	416.2	515	354.1	287.8	361
2016	1070.1	865.9	690	815.7	541.4	521

Table (14).Mean annual maximum temperature for the selected meteorological stations

Year	Amdework	Asketema	Sahla	Sekota	Tisiska	Abergele
1986	22.9	23.9	26.7	26.1	27.2	25.6
1987	23.0	24.4	28.0	27.0	28.1	27.6
1988	21.7	23.7	27.4	26.3	27.0	27.1
1989	21.6	23.2	27.6	25.8	26.5	26.4
1990	22.2	24.0	29.2	25.9	27.0	24.7
1991	22.4	23.0	27.9	25.2	27.2	26.7
1992	21.8	22.9	27.4	24.8	26.6	26.8
1993	21.2	22.7	26.9	25.2	26.1	25.9
1994	22.6	24.1	27.9	26.3	27.2	27.2
1995	22.8	24.2	28.4	25.0	27.1	27.4
1996	21.9	23.5	27.4	26.1	26.2	26.6
1997	22.8	24.2	28.6	25.6	27.5	27.6
1998	23.4	24.6	28.7	25.5	27.9	27.6
1999	23.0	24.3	28.4	25.3	27.3	27.4
2000	22.7	24.0	28.2	25.3	27.4	27.4
2001	23.2	24.2	28.7	25.8	27.5	27.7
2002	23.9	24.4	29.2	27.1	27.9	28.0
2003	23.4	24.0	28.8	26.7	27.5	27.7
2004	23.4	24.2	28.5	26.4	27.2	27.6
2005	22.9	23.9	28.2	26.1	27.1	27.4
2006	23.3	24.0	29.2	26.2	27.5	27.8
2007	23.4	24.3	29.5	26.5	27.9	28.2
2008	23.3	24.0	28.6	26.7	27.7	27.7
2009	23.9	24.4	28.9	27.4	30.0	27.5
2010	23.1	23.6	28.7	26.8	32.4	26.9
2011	22.9	23.3	27.9	26.7	26.4	26.3
2012	23.3	23.7	28.0	26.9	32.0	27.0
2013	23.1	24.8	28.8	27.0	33.8	28.0
2014	22.9	24.2	28.7	27.2	32.8	27.4
2015	26.5	28.3	32.7	27.7	34.2	33.4
2016	24.7	27.1	32.9	27.3	33.3	32.9

Table (15).Mean annual minimum temperature for the selected meteorological stations

Year	Amdework	Asketema	Sahla	Sekota	Tisiska	Abergele
1986	10.1	10.6	13.6	12.3	12.9	12.6
1987	9.8	10.3	12.8	12.0	12.7	12.9
1988	10.0	10.9	12.3	12.1	12.5	12.7
1989	8.8	10.4	12.1	11.9	11.9	12.3
1990	8.5	9.1	11.9	12.2	11.2	11.5
1991	10.3	10.7	13.6	12.1	13.0	13.1
1992	9.5	11.1	12.8	12.3	12.8	12.9
1993	9.3	10.1	12.0	11.6	12.1	11.9
1994	9.4	10.5	12.9	12.2	12.6	12.3
1995	9.4	10.5	14.0	11.7	13.0	12.9
1996	9.3	10.4	13.6	12.6	12.7	12.7
1997	9.8	11.1	13.4	11.7	12.6	12.7
1998	10.0	10.9	13.1	10.2	12.4	12.5
1999	9.3	9.6	12.6	12.0	11.6	11.8
2000	9.5	9.6	14.0	12.4	13.0	13.1
2001	10.2	10.3	14.1	12.6	13.4	13.8
2002	10.3	10.8	14.3	13.0	13.4	14.1
2003	10.5	10.9	14.3	13.2	13.3	14.0
2004	10.5	10.8	13.7	13.3	13.1	13.7
2005	9.6	10.7	13.3	13.6	12.7	13.2
2006	10.1	10.9	13.2	13.3	12.8	13.1
2007	10.1	11.0	13.4	13.3	13.1	13.0
2008	10.2	10.3	13.0	12.7	12.2	12.9
2009	11.8	10.9	13.9	12.6	13.2	13.3
2010	10.9	11.0	14.4	11.8	18.2	14.3
2011	11.3	10.6	14.2	10.7	13.0	13.8
2012	10.4	10.7	14.1	11.7	18.0	13.4
2013	11.3	12.0	14.4	13.1	14.3	13.8
2014	11.5	11.0	13.9	12.8	17.5	13.3
2015	11.2	13.6	16.2	12.9	18.7	18.2
2016	11.0	12.3	19.1	12.8	18.7	20.0

Table (16). Wheat production and Area under Cultivation in six Woreda

	Sekota		Amdework		Asketema		Tisiska		Sahla		Abergele	
	Wheat		Wheat		wheat		Wheat		wheat		Wheat	
Year	Area	pron	area	Pron	Area	Pron	area	Pron	Area	Pron	Area	Pron
2007	4040	16360	1667	18675	3120	26091	588.5	6355.8	539	4042	1043	10130
2008	2013	14519	3120	24091	1142	12790	702	2190240	420	2039	852	6592
2009	4222	26430	1361	10247	932	4942	480.5	654153	440.4	2033	837	6455
2010	2013	17117	1337	14443	916	9258	472	631206	432.7	3246	739	7377
2011	2247	8542	1181	10159	809	5906	416.9	492484	382.2	2582	1002	4221
2012	1829	15185	1601	13287	1096	11152	572	915177	517.9	5157	1037	9850
2013	1994	19540	1657	15905	1135	17939	592	980329	536	2074	1037	4398
2014	4296	39523	1657	12260	1135	13488	592	980329	536	4316	1037	6120
2015	4296	31361	1657	12615	1135	10488	591.7	980329	536	4016	1037	4158
2016	4296	58426	1682	22869	1863	25114	298	501117	536	5114	1037	8100

Table (17). Sorghum production and Area under Cultivation in six Woreda

	Sekota		Amdework		Asketema		Tisiska		Sahla		Abergele	
	Sorghum		Sorghum		Sorghum		sorghum		sorghum		Sorghum	
Year	Area	Pron	area	pron	Area	Pron	area	pron	Area	pron	area	Pron
2007	3801	Pron	7018	86323	1272	9586	2477	25761	2271	26112	5437.9	52204
2008	16632	20145	1272	8586	4806	43833	4082	31839	884	8485	4393.7	26362
2009	2082	105811	6454	41289	4421	20509	2278	12529	2088	18167	4040.8	25457
2010	16632	8278	9519	113281	6519	51019	3359	31246	3079	31414	5959.6	58404
2011	27361	121848	9289	80817	6362	41353	3279	31802	3044	29531	5815.6	38964
2012	7981	142279	6975	58587	4777	35252	2462	13051	2256	23919	4366.4	44974
2013	9983	90184	8735	80364	5982	80165	3083	14182	2867	19206	5437.9	30452
2014	9586	86853	8735	55032	5982	50285	3083	5858	2867	22646	5437.9	48397
2015	9586	55599	8735	46297	5982	45467	3083	15415	2867	18346	5437.9	22839
2016	12637	45054	11233	153892	6983	71227	7723	43249	3180	31164	7723	47110

Table 18: Future yield change (%) for wheat and sorghum at the studied area for the period 2050s and 2080s under Rcp4.5 and 8.5 relative to the base period

District	Wheat				Sorghum			
	Rcp4.5		Rcp8.5		Rcp4.5		Rcp8.5	
	2050s	2080s	2050s	2080s	2050s	2080s	2050s	2080s
Amdework	-22.73	-23.49	-20.35	-22.65	-13.9	-14.3	-10	-11
Asketema	3.28	10.84	23.1	28.3	-3.54	3.76	4.88	20.79
Sahla	-13.26	-14.49	-10.62	-16.22	12.38	12.59	15.85	14.94
Sekota	-11.61	-5.85	-5.05	2.72	-13.65	-11.78	-12.11	-13.34
Tisiska	7.97	9.21	16.51	16.04	14.98	14.79	17.59	17.97
Abergele	4.35	5.24	14.30	-36.74	-4.25	-3.95	2.53	6.97
Average	-6.1	-4.9	-2.4	-1.2	-1.3	1.3	2.6	9.1

Table19.The indices of regression goodness fit calculations

$$R^2 = 1 - \frac{SSE}{SST}, SSE = \sum_{i=1}^n (y_i - \hat{y}_i)^2, SST = \sum_{i=1}^n (y_i - \bar{y})^2$$

$$SE = \sqrt{MSE}, MSE = \frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2$$

$$F = \frac{MSR}{MSE}, MSR = \frac{SSM}{DFM}, SSM = \sum_{i=1}^n (\hat{y}_i - \bar{y})^2$$

Where R^2 is coefficient of determinations, SSE=sum square errors, SST= sum square total

MSE is mean square error, MSR is mean square for regression, SSM=sum square for model

DFM is degree of freedom for model, n is number of points, y_i observed values, $\hat{y}_i$ is predicted value